THE PRACTICE OF LUBRICATION

THE PRACTICE OF
LUBRICATION

AN ENGINEERING TREATISE

ON

THE ORIGIN, NATURE AND TESTING OF LUBRICANTS, THEIR SELECTION, APPLICATION AND USE

BY

T. C. THOMSEN, B.Sc. (Copenhagen) M.I.Mech.E., etc.

Managing Director, T. Krüger, Ltd., Copenhagen, Denmark; Independent Consulting Lubricating Engineer. For Many Years Chief Engineer to the Vacuum Oil Company, Ltd., London; Late Research Engineer to the Anglo-Mexican Petroleum Co., Ltd.

THIRD EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK AND LONDON
1937

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

TO ALL THOSE WHO STRIVE TO
ADVANCE THE SCIENCE OF LUBRICATION,
RAISE THE STANDARDS OF LUBRICANTS,
AND IMPROVE THE METHODS OF THEIR
APPLICATION AND USE
THIS BOOK IS DEDICATED

PREFACE TO THE THIRD EDITION

The development which has taken place in all directions since the previous edition of this book has necessitated considerable alterations and the addition of new matter.

In producing lubricating oils, the oil refiner is less dependent than hitherto on the nature of the crude oil. By means of newer and improved refining methods, he can eliminate undesirable constituents in the oil more efficiently than was formerly the case. It has thus become possible to obtain with greater ease, and from a greater variety of crudes, lubricating oils with noncarbonizing and nonemulsifying properties.

Of new ideas which are developing may be mentioned extreme pressure lubricants and the addition of anticorrosion inhibitors to automobile oils. Colloidal graphite is also finding more extensive use.

The development of lubricating oils appears to be in the direction of producing inert lubricating media of suitable viscosities, media which will withstand the action of water (nonemulsifying property), air (nonoxidizing property), heat (noncarbonizing property), and cold (good cold test), and which, mixed with a small percentage of "very oily" constituents, are given the desired oiliness.

In measuring devices, efforts are being made to construct a satisfactory commercial viscometer for measuring absolute viscosity.

The nature of friction and character of frictional surfaces are constantly being studied, and although this question still presents many problems, considerable progress is recorded.

In the mechanical field, an important development is the "Nomy" bearing principle, which appears to open up great possibilities for longer life and exceedingly low frictional losses for all types of bearings.

A marked development has taken place inside the field of internal-combustion engines in the direction of better, cleaner,

and more economic lubrication (*e.g.*, modernized forms of piston rings, and scraper rings).

The ever-widening use of circulation oiling systems for all high-speed engines and machinery has brought about an increased use of centrifugal oil purifiers and, in certain fields, streamline oil filters.

T. C. THOMSEN.

COPENHAGEN, DENMARK,
August, 1937.

PREFACE TO THE FIRST EDITION

Lubrication has for many years received only scant attention, and existing standards of lubrication still leave considerable room for improvement. Very few firms employ qualified chemists to assist them in maintaining a reasonable standard of efficiency; and such a thing as technical service embodying a highly trained staff of lubricating engineers was unheard of until recent years and is still considered an expensive luxury by most firms.

A development is, however, gradually taking place in the right direction. Both oil suppliers and oil users are beginning to realize that lubrication can no longer be left to guesswork; that to send salesmen out with a set of samples and a price list but without the necessary technical knowledge or backing is to court failure; that entertaining customers or obtaining business simply through friendship between salesman and buyer is not sufficient, because friendship does not add to the lubricating value of the oil, nor does it always help to select the right oil or use it in the right way.

Lubrication is rapidly becoming a science. Some oil firms have appreciated the value of the assistance of a staff of qualified lubricating engineers, who should be able to inspect a plant, to report intelligently on the lubrication conditions of all engines and machinery, to point out and estimate the value of possible improvements in regard to savings in power or lubricants, to investigate complaints, etc. These men should have a thorough knowledge of their firms' products, so that they can recommend the correct grades for any kind of machinery, even without knowing anything about the lubricants actually in use.

Obtaining samples for analysis and "matching" them at a lower price per gallon is unfortunately still the standard of procedure of most oil firms and should be discouraged by the consumer in favor of a more efficient lubrication service, which places the supply of lubricants on a sound engineering basis.

Large consumers of lubricants will find it worth their while to ask oil suppliers to demonstrate the value of their lubricants; and they will soon find that it is of far greater importance than

is generally realized that the lubricating systems of the engines or machinery be as perfect as possible; that the correct grades of lubricant be selected; that the lubricants be stored and distributed in the best manner, used in the right way and in the right amount; and that the waste oil, if any, be collected, purified, and used again.

Oil firms who intend to develop a technical organization must not make the mistake of thinking that they can engage any kind of engineers. A high standard of general engineering knowledge is essential, besides considerable tact in dealing with consumers.

Furthermore, an engineer, however excellent his general knowledge, does not become a lubricating engineer the moment he is engaged by an oil firm. He will have to study the available literature but must not expect to develop his experience by sitting in the office. He should study closely lubrication of machinery under actual working conditions to the minutest details, and thus he will in time accumulate the right kind of special knowledge and develop the right instinct to enable him to render first-class service and to add his effort, be it great or small, to the advancement of the science of lubrication.

The lubricating engineer needs good assistance from the chemical laboratory in analyzing oils, deposits, etc. On the other hand, chemists should not be expected nor should they be allowed to make recommendations, except in consultation with an engineer, who is able to investigate and judge the importance of the mechanical and operating conditions of the plant, which is essential in order to interpret correctly the value of the laboratory's findings.

The oil manufacturer, through lubricating engineers, must watch constantly the results obtained under working conditions by the various standard grades of lubricants, and he will in this way accumulate knowledge as to the value and range of service of each particular grade; he will also find out possible weaknesses, and the engineering staff in conjunction with his chemical staff will be able to point the way to remedy.

Oil firms who have developed an efficient technical staff will always have a great advantage over other firms who are less well equipped. Their salesmen having the benefit of technical assistance will easily command greater sales than their com-

petitors. Even if their products are no better, they will yet be able to render to their customers better service, because they know how to select the correct grades and can indicate to the consumer how the maximum value of these grades can be obtained. Such service always brings credit and good will to the oil supplier and demonstrates to the consumer that lubrication service comprises a great deal more than is indicated by the price per gallon.

The chief engineer or master mechanic of a works cannot be expected to know everything there is to know about lubrication; it is no discredit to him if he gains a few points by discussing the lubrication of his plant with lubricating engineers who have made a life study of the subject.

The author hopes that oil firms who have no engineering staff will see the necessity of developing a technical service, sufficient for their needs in keeping with modern sales methods, which are directed toward selling lubrication, rather than lubricants, or selling experience and knowledge rather than selling oils on a price-per-gallon basis.

The subject of lubrication is intimately connected with the mechanical and operating conditions of engines or machinery. The author has therefore endeavored to present for each type of engine or class of machinery the "technical background," without which it is futile to attempt to focus the lubricating problems, as seen by the engineer or the chemist, and without which it is impossible to determine the character of the oils required to give the best service.

The author is well aware of the magnitude of such a task and the many shortcomings of the present work, but he ventures to hope that the way in which he has dealt with the problems and endeavored to convey his experience may prove of some value in stimulating others to take a deeper interest in lubrication matters and in helping them to get a clearer view of possible problems or difficulties and their solution.

Mechanical and *electrical engineers* in charge of plant and *lubricating engineers* as well as *general consulting engineers* will, the author hopes, find some food for thought; they may not always agree with the theories and views put forward, which are often novel or even contrary to traditional opinions; but in that case the author would urge them to try out his recommendations,

which are based on many years of practical experience in many parts of the world; they will then be able to draw their own conclusions, and constructive criticism will always be welcomed by the author and gratefully received.

Engine builders, it is hoped, will find information which will prove useful to them in equipping their engines and machinery with correctly designed lubricating systems and appliances and in giving their customers sound advice or instructions with reference to the grades of lubricants required and the best manner of using them.

Oil chemists and manufacturers and chemists employed by oil consumers will, it is hoped, find the book helpful in pointing out the conditions under which lubricants have to work for particular types of machinery and the influences, such as oxidation, and emulsification, to which they are subjected during use. The author has endeavored to focus the problems and describe the mechanical conditions in such a manner as to assist chemists in deciding which are the physical and chemical tests of greatest importance in each particular case.

References are given throughout the text to special sources of information, but the author wishes particularly to record his indebtedness to Mr. L. Archbutt for analyses of graphites; to Mr. J. Hamilton Gibson for photographs of streamlines in connection with Michell's thrust blocks; to Mr. I. L. Langton for information regarding dielectric strength of transformer oils; to *The Engineer* for permission to make use of some articles by the author on lubrication of modern turbines; to Mr. E. W. Johnston for information regarding the use of Aquadag in steam engines; to the Vacuum Oil Company of New York for raising no objection to the author's making use of several technical papers, which he prepared during the time he was associated with that company as chief engineer in London; to the Controller of His Majesty's Stationery Office for permission to make use of *Bulletin* 2 on cutting lubricants and cooling liquids and *Bulletin* 4 on solid lubricants, both of which have been published by the Department of Scientific and Industrial Research and the material for which was prepared by the author; and to Mr. W. A. E. Woodman for valuable assistance in preparing many of the drawings.

LONDON, ENGLAND,
August, 1920.

T. C. THOMSEN.

CONTENTS

THE PRACTICE OF LUBRICATION

CHAPTER I

MINERAL LUBRICATING OILS

PETROLEUM CRUDE

Oil Wells.—Petroleum crudes are secreted by nature and are found in many countries all over the world.

Occasionally, petroleum crude is found lying on the surface of water in pools, but usually it is found at various depths in the earth, from a few hundred feet up to as much as five thousand feet. To bring the crude to the surface, a hole is drilled, varying in diameter from a few inches up to 30 in., according to the depth.

It is usual to find confined with the oil a large amount of gas under great pressure, which may be as high as 800 lb. per square inch. Owing to this pressure the oil when first reached is forced up the bore hole and rises many feet in the air; such a well is called a "gusher."

Some gushers have produced enormous quantities of crude oil, for example, the Potrero No. 4 well drilled in 1910 by the Mexican Eagle Oil Company. This well was capable of giving about 120,000 bbl. of crude oil daily but now delivers only salt water.

When the gas pressure is sufficiently reduced in an old well, it is no longer a "flowing well" but becomes a "pumping well," and the output is reduced to a small fraction of its former value.

Production of Petroleum Crude.—The production of crude oil amounts to approximately 300 million tons per annum. Of this production, 63 per cent is supplied by the United States, 16 per cent by Central and South America, 12 per cent by Europe, and 9 per cent by Asia.

United States.—The production is still increasing in the United States; many of the old American fields (Pennsylvania, etc.) are becoming exhausted, but those in California and Oklahoma have made up for the decreased production in the older fields.

Russia.—Production has considerably increased after the World War, but exports have of late years decreased owing to largely increased home consumption.

Mexico.—The Mexican oil industry has developed rapidly since 1908. The potential resources are enormous, being probably as great as or even greater than the resources of the United States.

South America.—New oil fields of considerable importance have been opened up in Peru, Venezuela, and Colombia.

Persia.—Large oil fields have been developed, and the output is increasing rapidly, particularly after building a large pipe line which connects the oil fields with the seacoast.

Origin of Petroleum Crude.—Three theories are held concerning the origin of crude oils, but none is universally accepted.

1. *Inorganic Theory.*—According to this theory, petroleum is produced deep down in the crust of the earth by the action of high temperature and pressure on the minerals found there; carbon and hydrogen are supposed to have combined and formed the hydrocarbons which are the chief constituents of petroleum crude. Only a minority of geologists favor this theory.

2. *Vegetation Theory.*—According to this theory, vegetable matter has been covered by a layer of impervious material; the air thus being excluded, rotting was prevented, and slow decay during hundreds of thousands of years transformed the vegetable matter into petroleum crude oil and petroleum gas. Several geologists favor this theory.

3. *Marine-animal Theory.*—According to this theory, dead fishes or tiny marine animals with calcareous shells were covered over by a layer of impervious material, and their organic parts have gradually been transformed into crude oil and gas. Most geologists favor this theory.

Whichever theory is correct, it seems certain that the world's stocks of petroleum crude are practically complete and are being rapidly consumed.

Composition and Character of Petroleum Crude.—When the crude comes to the surface it often contains water (frequently

salt water) and sand, which are separated out in large collecting and settling reservoirs.

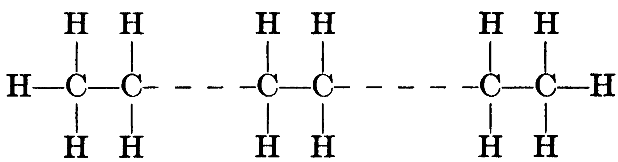
The crude is rarely transparent; the color is usually dark brown or black.

Petroleum crude consists chiefly of carbon (C) and hydrogen (H) in the form of hydrocarbons. Besides carbon and hydrogen, there is usually also a certain amount of oxygen, nitrogen, and sulphur present.

The percentages of the various chemical constituents vary within limits, as indicated in the following table:

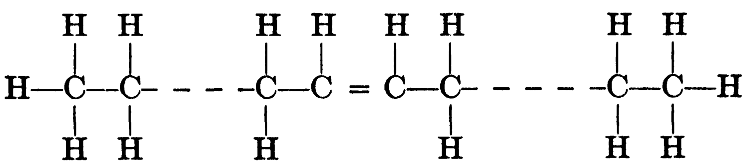
	Per Cent
Carbon	81.00 to 88.0
Hydrogen	10.00 to 14.0
Oxygen	0.01 to 1.2
Nitrogen	0.002 to 1.7
Sulphur	0.01 to 5.0

Hydrocarbons. *Paraffins* (C_nH_{2n+2}).—The molecules of these hydrocarbons are bound together in the form of chains and are members of the large family of hydrocarbons known as open-chain hydrocarbons, thus:



As all the carbon atoms are fully engaged, each carbon atom being tetravalent and attached to four other atoms, the paraffins are called saturated hydrocarbons.

Olefins (C_nH_{2n}).—The olefins are also open-chain hydrocarbons, but their molecules have two atoms of hydrogen less than the paraffins, thus:



They are called unsaturated, because they are capable of absorbing hydrogen, oxygen, sulphur, etc., to a value equivalent to 2 atoms of hydrogen per molecule.

Naphthenes (C_nH_{2n}).—Naphthenes are closed-chain hydrocarbons; they have the same chemical formula as the olefins, except that the atoms are not arranged in the form of open chains but more in the nature of rings or closed chains, in such a manner as to saturate all the carbon atoms.

Naphthenes being saturated hydrocarbons are consequently more stable than the olefins.

C_nH_{2n-2}, C_nH_{2n-4}, Etc.—Most hydrocarbons of the formulas C_nH_{2n-2}, C_nH_{2n-4}, etc., are more or less unsaturated, and the more so the less hydrogen they contain.

Hydrocarbons having from 1 to about 15 carbon atoms per molecule represent the light products of petroleum crude, *viz.*, petroleum gas, gasolines, kerosenes, and light transformer and spindle oils.

Most lubricating oils are mixtures of hydrocarbons possessing more than 15 carbon atoms per molecule; the greater the number of carbon atoms the greater is the viscosity of the oil. Comparing two hydrocarbons having the same number of carbon atoms, the one containing the least hydrogen is the more viscous of the two, but its viscosity is less stable; *i.e.*, it changes more rapidly with changes in temperature.

Most petroleum crudes are very complicated in character, and it is difficult to classify them; they contain hydrocarbons of practically all types, but the proportions vary considerably according to the origin of the petroleum.

Petroleum crudes are, however, referred to as paraffin-base crudes, naphthenic crudes, asphaltic-base crudes, and mixed-base crudes.

Paraffin-base crudes are so called because they contain paraffin hydrocarbons (C_nH_{2n+2}). There are only a few lubricating oils of low viscosity which are actually paraffin hydrocarbons, as paraffins from $C_{17}H_{36}$ and upward represent the hydrocarbons present in paraffin waxes. The heavy-viscosity lubricating oils which are found in paraffin-base crudes are largely composed of olefins and naphthenes (C_nH_{2n}) and acetylenes (C_nH_{2n-2}). As paraffin-base crudes always contain a certain amount of paraffin wax, usually about 2 per cent, lubricating oils made from such crudes have high setting points.

The most important supplies of paraffin-base crudes come from Pennsylvania and Ohio in the United States. They are fairly

fluid; rich in gasolines and kerosenes; usually contain only a little asphalt, sulphur, oxygen, or nitrogen; and have a low specific gravity.

Naphthenic crudes consist chiefly of naphthenes (C_nH_{2n}); they also contain a small percentage of acetylene hydrocarbons (C_nH_{2n-2}).

Russian and some South American crudes belong to this class and contain little or no paraffin wax, hence produce lubricating oils with low setting points.

Asphaltic-base crudes are so called because they contain a large amount of asphalt; they usually contain certain small percentages of sulphur, oxygen, and nitrogen. The crudes from California, Mexico, Texas, and South America belong to this class.

They are very viscous; black in color; rich in lubricating oils, fuel oils, and asphalt; and have a high specific gravity; they often contain complex sulphur compounds, which are difficult to extract.

The lubricating oils produced from nonparaffinic asphaltic-base crudes are naphthenic in character, have low setting points, and possess a wide range of viscosity, ranging from quite thin to exceedingly viscous oils.

The hydrocarbons in asphaltic-base crudes are lower in hydrogen than the paraffins, although paraffins are often present. For example, *California crudes* contain olefins (C_nH_{2n}), asphaltic hydrocarbons (C_nH_{2n-4}), and also some aromatic compounds (C_nH_{2n-6}).

Mixed-base crudes are crudes of a character intermediary between paraffin-base crudes and asphaltic-base crudes, containing both paraffin wax and asphalt. Mexican crudes are the most important mixed-base crudes.

DISTILLATION AND REFINING

Petroleum crude is a mixture of many hydrocarbons, all having different boiling points.

The separation of all these hydrocarbons—from the lightest gasoline to the heaviest lubricating oils—is done by means of distillation and subsequent condensation of the various "fractions." The old *intermittent system* by which batches of, say, 1,000 bbl. of crude oil were distilled in individual stills has rapidly been replaced by the modern *continuous system of distillation*. In this

system, the crude oil is pumped through nests of tubes which are heated by oil fire. Notwithstanding that the crude oil passes very rapidly through the tubes, it becomes heated to such a high temperature that the latent heat is about sufficient to evaporate it completely. When it next passes over—"flashes"—in one or several towers, broken dephlegmation of the vapors takes place, while the nonevaporated residue collects and may be drawn out at the bottom of the tower.

In order to regulate the dephlegmation, it is customary to introduce superheated steam or kerosene vapors at one or more places in the tower.

Cracking.—The crude itself or certain distillates are "cracked" when it is desired to produce the maximum amount of light fractions. When hydrocarbons are suddenly heated to a temperature above their boiling points and not given time to distill in the ordinary way, they decompose into simpler hydrocarbons which possess lower boiling points; this process is called "cracking."

Cracking is now practiced according to two different principles:

1. *Liquid Cracking.*—The heavy oil is rapidly heated in the liquid state—the lighter constituents evaporate—the residue is again heated, etc., until the maximum amount of light oil is produced.

2. *Vapor Cracking.*—The heavy oil is evaporated; the vapors are led through a reaction chamber in which they are exposed to high temperatures. The light fractions thus produced are separated out by dephlegmation, while the heavier fractions are again evaporated and sent through the reaction chamber.

Most cracking methods now employed operate according to the foregoing principles or a combination of these. Often the process finishes by refining, the oil vapors passing through fuller's earth or other refining chemicals.

By cracking, a large amount of aromatic and unsaturated hydrocarbons are formed; aromatic compounds in gasoline mean high "antiknock value" (a high octane index), which makes such gasolines specially suitable for use in high-compression gasoline engines.

Steam Distillation.—When it is desired to produce the maximum amount of lubricating oils and minimize cracking, live superheated steam is introduced into the stills, mixing intimately with the oil.

To increase further the yield of lubricating oils, and to prevent overheating, the oil may be distilled under a partial vacuum, as the vacuum causes the various fractions to distill over at temperatures lower than their normal boiling points.

When the distillation is assisted by the application of steam with or without vacuum, a lower percentage of unsaturated hydrocarbons is formed than when distilling without steam, and less acid or other treatment is therefore required when refining the distillates.

Redistillation.—Usually, the crude is split into only a few fractions, which may be further separated into a greater number of fractions by redistillation.

Lubricating distillates are also redistilled and thus separated into heavier and lighter lubricating oils. The redistillation now nearly always takes place in towers under high vacuum and with application of superheated steam. With certain systems a vacuum as high as 0.1 mm. Hg is employed.

Extraction.—During late years, methods have been devised whereby lubricating oils are extracted direct from the crude oil, *e.g.*, by mixing with propane and phenol. The liquid propane separates out the asphaltic matter, and the phenol extracts the aromatic and naphthenic constituents, leaving an oil more or less paraffinic in character, according to how much of the aromatic and naphthenic contents is extracted.

By these methods, even a Texas crude may be divided into fractions of naphthenic as well as paraffinic character.

PETROLEUM PRODUCTS

When the light fractions, *viz.*, gasolines (distilling up to 150°C.) and kerosenes (distilling between 150 and 300°C.), have been distilled off, the next distillate is a high-flash burning oil called "300 fire-test" oil, mineral colza, mineral sperm, or mineral seal; but if the quality of this distillate is not such as to produce a satisfactory burning oil, the distillate is called "solar oil" or "gas oil" and is used for making oil gas or carbureted water gas or as a high-class fuel oil for semi-Diesel or Diesel oil engines. Also, when mixed with heavy black residual oils (asphaltic or non-asphaltic) it is used as fuel oil in Diesel engines or in furnaces using liquid fuel.

The *lubricating-oil* fraction or fractions (from which spindle oils, engine, and machinery oils are manufactured) now distill over; and if the crude contains wax, the distillate containing wax is chilled to about 20 to 25°F., and in the wax filter press the oils are squeezed out, and the wax left in the press. Lubricating oils made from a paraffin-base crude, therefore, have setting points of about 20 to 25°F. unless they are specially treated to remove more of the wax; they may also be blended with other oils having very low setting points so as to produce oils with low setting points.

In modern refineries, the *wax* is often removed by dissolving the oil in gasoline or chlorinated hydrocarbons, cooling the solution, and subsequently separating the wax in special centrifugal separators. When employing gasoline, it is possible to remove only the amorphous wax continuously, but with chlorinated hydrocarbons, which are heavier than the oil, it is possible continuously to separate crystalline as well as amorphous wax.

After centrifuging, the solvent is distilled away, and an oil remains with a cold test which bears a relation to the temperature to which the mixture was cooled and to the amount of solvent employed.

The cold test of an oil may also be reduced by adding to it so-called inhibitors, *e.g.*, *Paraflow*. The effect of such inhibitors is that, when the oil is cooled, the wax solidifies or crystallizes in the form of very small particles which do not touch each other but merely float about, so that the oil remains fluid.

The *crude wax*, whether produced by filter presses or by centrifuging, contains a certain amount of oil (up to 50 per cent), which is removed by "sweating," *viz.*, slow prolonged heating of the wax. The melting points of the sweated wax range from 100 to 130°F.; it is melted, crystallized in molds, and sold as white paraffin wax used chiefly for making candles, also for preserving fruit and jellies, for polishing floors, etc.

The pressed or centrifuged lubricating oils are redistilled into heavier and lighter oils and either (1) treated by sulphuric acid or anhydrous aluminium chloride or (2) filtered through fuller's earth, or high-activated fuller's earth, in order to remove unstable hydrocarbons or other undesirable elements and to lighten the color.

When filtered through fuller's earth or animal charcoal, the first few gallons of oil that come out are colorless; but as the filtering material becomes saturated with the absorbed impurities and coloring matter, the color of the oil gradually darkens. Each grade of oil is filtered to be within the standard color limits for that particular grade.

Dark Cylinder Stock.—The residue of some crude oils from distillation is a very heavy viscous dark oil used principally for internal lubrication of steam-engine cylinders and valves. If it contains much more than a trace of asphalt, it should not be used for this purpose but may be mixed with light-viscosity lubricating oils to produce dark lubricating oils.

Filtered cylinder stock is produced from dark cylinder stock by filtration; the color becomes green-amber; the heavy-gravity tarry matter is removed; the viscosity is reduced 15 to 25 per cent; and the specific gravity is likewise reduced, but the setting point is increased.

Bright stock indicates normally a filtered cylinder stock, from which wax has been specially removed, but there are also a good many very viscous distillates on the market which are sold under this name.

Petroleum jelly (mineral jelly, petrolatum) is an amorphous wax produced by slow cooling of dark cylinder stock diluted with gasoline; the petroleum jelly separates out and is afterward refined (decolorized) by hot filtration. Petroleum jelly is used in the manufacture of cordite (an addition of 2 per cent of jelly makes the cordite less brittle), as an antirust grease, for ointments (veterinary purposes), etc. Vaseline is the proprietary name given to a certain high-grade petroleum jelly.

Cold-test Cylinder Stock.—By distilling off the gasoline from the liquid portion a *low cold-test cylinder stock* is produced, which may be further refined by filtration.

The best *cylinder stocks* are almost exclusively produced from paraffin-base crudes.

When asphaltic-base crudes are distilled, cylinder stock can rarely be produced; the residue consists of asphaltic matter. Heavy liquid asphaltic residues are used as *road-spraying material* in place of coal tar and are also used in the manufacture of various *liquid fuels.*

Petroleum pitch or *bitumen* has found a most important use, chiefly in the making of wearing surfaces for modern roads, also for roofing felts, bituminous paints, etc. It is also used in the making of hot-neck greases for steelworks rolling mills.

When the liquid bitumen in the stills is "blown" with air, it oxidizes into blown asphalt, which has a rubbery nature and finds an important use as rubber substitute, for roofing felt, etc.

CLASSIFICATION OF LUBRICATING OILS

Dark Cylinder Oils.—Dark cylinder oils are the undistilled dark residues left in the stills (by steam distillation chiefly of nonasphaltic crude), freed from solid impurities but not filtered. They are used chiefly for lubrication of steam-engine cylinders and valves, either alone or mixed with from 3 to 10 per cent of acidless tallow oil. The ordinary characteristics are as follows:

Flash point open	From 500 to 620°F.
Specific gravity	From 0.900 to 0.940
Viscosities	Nos. 11 to 16 (see page 57)
Color in reflected light	Dark brown or dark green to black
Color in transmittent light	Dark brown to black
Setting point	25 to 60°F.

Filtered Cylinder Oils and Bright Stocks.—They represent the highest quality oils used for internal lubrication of steam engines; they are used either alone or mixed with from 3 to 12 per cent of acidless tallow oil. They are also used largely for mixing with lower viscosity oils to produce heavy-viscosity oils for internal-combustion engines or heavy-viscosity engine and machinery oils, air-compressor oils, circulation oils, etc.

Flash point open	From 490 to 580°F.
Specific gravity	From 0.875 to 0.930
Viscosities	Nos. 11 to 15 (see page 57)
Color in reflected light	Green, amber
Color in transmittent light	Deep red
Setting point	15 to 80°F.

Ordinary lubricating oils are distilled or extracted and then refined and filtered.

The heavier engine or machinery oils may also be produced by mixing the lighter oils with filtered cylinder oil or bright stock.

Ordinary lubricating oils represent the great bulk of the oils used for general external lubrication of all kinds of engines and machinery.

Every oil refinery of importance may be relied upon to produce lubricating oils for such general purposes as fulfill all reasonable ordinary chemical and physical requirements, such as viscosity, cold test, flash point, freedom from acidity, etc.

One may divide this group into two typical groups, *viz.*, spindle and light machinery oils and heavy engine and machinery oils, having the following characteristics:

Spindle and Light Machinery Oils.—They are light to medium in viscosity and are used for quick-running machinery, such as textile machinery, high-speed shafting, electric motors; and also for manufacturing yellow lubricating greases:

Flash point open	275 to 420°F.
Specific gravity	0.870 to 0.910
Viscosities	Nos. 1 to 8 (see page 57)
Color	Pink to red
Setting point (paraffin base)	15 to 25°F.
Setting point (asphaltic base)	0 to 15°F.

Heavy Engine and Machinery Oils.—They are of high viscosity and used for slower running engines and machinery and for heavier bearing pressures.

When mixed with from 5 to 20 per cent of fixed oil (blown or unblown) they produce some of the lighter viscosity marine- and railway-engine oils:

Flash point open	380 to 440°F.
Specific gravity	0.900 to 0.930
Viscosities	Nos. 9 to 12 (see page 57)
Color	Red
Setting point (paraffin base)	20 to 30°F.
Setting point (asphaitic base)	0 to 20°F.

High-grade lubricating oils are needed for such purposes as circulation lubrication of steam turbines and high-speed enclosed-type steam engines, internal lubrication of air compressors, refrigerator compressors, all kinds of internal-combustion engines, etc.

Great knowledge and experience are required on the part of the oil refiner to produce oils for such exacting requirements and to

keep pace with the never ending development of modern engines and machinery.

The oils are exposed to such influences as extreme heat or cold, oxidation, emulsification, electric action, all of which will be discussed later when the various types of modern engines and machinery are described.

The difference between *ordinary* and *high-grade* oils lies chiefly in that the latter are the outcome of extreme care all the way from selecting the crude to the final treatment, with a view to giving the oil just those special properties which are desired for the particular service in question.

It is obvious that no oil refinery can manufacture high-grade oils without a full knowledge of the conditions under which high-grade oils are expected to operate and that, in consequence, there must be close cooperation between the refinery chemists and the service engineers.

Dark Lubricating Oils.—Dark lubricating oils are such undistilled residues from the crude or from the redistillation of lubricating oil distillates that, because of too low a viscosity or for other reasons, are considered unsuitable as cylinder oils. Dark lubricating oils are usually mixtures of such residues with low-viscosity lubricating oils to produce the required viscosity.

Dark lubricating oils are used for rough machinery in collieries and steelworks, as cheap oils for lubricating the axles of railway carriages, and for making black lubricating greases for rough service.

Flash point open............	300 to 450°F.
Specific gravity.............	0.890 to 0.950
Viscosities.................	Nos. 10 to 13 (see page 57)
Color.......................	Dark green or brown to black
Setting point...............	10 to 60°F.
Asphalt.....................	Less than 5 per cent

Bloomless Oils.—Bloomless oils are neutral oils that have been highly filtered (not acid treated) and may also have been sun bleached; they are very light in color and of light viscosity.

To have the bloom entirely removed, they must be treated with nitronaphthalene or other chemicals.

Bloomless oils are used for adulterating edible oils; also in the manufacture of "stainless" loom and spindle oils.

White Oils.—White oils are pale spindle oils which have been treated with fuming sulphuric acid or liquid sulphur dioxide, fuller's-earth filtration, etc., in order to remove the color completely. They are easily made from Russian crudes and are largely used as transformer oils. It is very difficult to remove color entirely from oils produced from paraffin-base crudes.

Medicinal White Oils.—Medicinal white oils are white oils that have been so treated as to remove not only color but also all taste and odor.

CHAPTER II

FIXED OILS AND FATS

Vegetable Oils and Fats	Animal Oils and Fats
Castor oil	Tallow
Rape oil	Tallow oil
Blown rape oil	Lard oil
Cottonseed oil	Neat's-foot oil
Blown cottonseed oil	Sperm oil
Linseed oil	Whale oil
Olive oil	Porpoise oil
Coconut oil	Dolphin oil
Palm oil	Melon oil
Palm-kernel oil	Menhaden oil
Peanut oil	Cod oil and other fish oils
Mustard oil	Wool grease
Rosin oil	

Animal and vegetable oils are called "fixed" oils because they cannot, like mineral oils, be distilled without decomposition. They also differ from mineral oils in that they contain from 9.4 to 12.5 per cent oxygen.

The distinction between fixed oils and fats is only a matter of temperature; all fixed oils become fats at or above 0°F., and all fats become oils at or below 125°F.

Animal oils are obtained by heating the fatty tissues of animals, *i.e.*, by "rendering" the fat or by boiling out the fatty oil with water. Vegetable oils occur mostly in the seeds or fruits of plants or trees and are obtained either by pressing or by chemical extraction with solvents. Animal oils are usually either colorless or yellow. Vegetable oils are colorless, yellow, or slightly green (chlorophyll present).

All fixed oils are devoid of bloom except rosin oil, and each variety generally has a distinctive odor, by which it can be identified. Their specific gravities range from 0.860 to 0.970. Rosin oil is an exception; its specific gravity may be as high as 1.0. Sperm oil has the lowest viscosity of all fixed oils, and castor oil the highest, but each kind of oil has its own peculiar viscosity, which varies only slightly.

All fixed oils have a tendency to combine with oxygen and, as a result, are sooner or later converted into solid elastic varnishes. As a result of this tendency, cotton waste, when saturated with fixed oils or lubricating oils very rich in fixed oils, has been known occasionally to heat gradually and finally to burst into flame. Dirty cotton waste, which contains fixed oil, must therefore be kept in receptacles with closed lids.

When the tendency to absorb oxygen is marked, the fixed oils are called drying oils, *e.g.*, linseed oil. When the tendency is moderate or only slight, the oils are called semidrying or nondrying oils, respectively, and it is only from these two types of fixed oils that lubricants are selected.

Mineral lubricating oils are practically free from any tendency to oxidize and therefore do not readily gum or develop acid as

FATTY ACIDS OCCURRING IN FIXED OILS
(*Journal of Society of Chemical Industry*, Vol. XVIII, p. 346, 1899.)

Series	Name of acid	Formula	Occurs chiefly in
	Isovaleric	$C_5H_{10}O_2$	Porpoise oil
	Caproic	$C_6H_{12}O_2$	Coconut oil
	Caprylic	$C_8H_{16}O_2$	
Acetic $C_nH_{2n}O_2$	Capric	$C_{10}H_{20}O_2$	
	Lauric	$C_{12}H_{24}O_2$	
	Myristic	$C_{14}H_{28}O_2$	
	Palmitic	$C_{16}H_{32}O_2$	Palm oil, also tallow, olive oil, and coconut oil
	Stearic	$C_{18}H_{36}O_2$	Tallow, also palm, castor, and rape oils
	Arachidic	$C_{20}H_{40}O_2$	Earthnut, rape, and mustard oils
	Lignoceric	$C_{24}H_{48}O_2$	
Oleic $C_nH_{2n-2}O_2$	Oleic	$C_{18}H_{34}O_2$	Olive oil and the animal oleins
	Rapic	$C_{18}H_{34}O_2$	Rape oil
	Erucic	$C_{22}H_{42}O_2$	
Linolic $C_nH_{2n-4}O_2$	Linoleic	$C_{18}H_{32}O_2$	The drying oils, also in olive and palm oils
Recinoleic $C_nH_{2n-2}O_3$	Ricinoleic	$C_{18}H_{34}O_3$	Castor oil
	Isoricinoleic	$C_{18}H_{34}O_3$	
$C_nH_{2n}O_4$	Dihydraxystearic	$C_{18}H_{36}O_4$	Castor oil

fixed oils do, which may lead to corrosion of the bearing surfaces.

All fixed oils are chemical combinations of alcohol radicles and fatty-acid radicles. The character of fatty acids is indicated in the table on page 15. The alcohol radicle occurring in the vegetable oils and most of the animal oils is glyceryl (C_3H_5), which is trivalent and therefore combines with three fatty-acid radicles. Olein, for example, which is the chief constituent of many fixed oils, such as tallow, lard, neat's-foot and olive oils, has the chemical formula $C_3H_5(C_{18}H_{33}O_2)_3$, in which C, H, and O signify carbon, hydrogen, and oxygen atoms, respectively. Stearin [$C_3H_5(C_{18}H_{35}O_2)_3$] and palmitin [$C_3H_5(C_{16}H_{31}O_2)_3$] predominate in solid fats; olein, in the fluid oils. It will therefore be seen that the nature of the fatty-acid radicle determines the character of the fixed oil.

Sperm oil is made up differently, being known as a liquid wax. All fixed oils, however, can be split up into alcohols and fatty acids by heating with water under pressure, by heating with sulphuric acid, by heating with alkalies, etc. By treatment with alkalies the fixed oils are said to be saponified. For example, by heating olein with water under pressure, the following change takes place:

$$\underset{\text{Olein}}{C_3H_5(C_{18}H_{33}O_2)_3} + \underset{\text{Water}}{3H_2O} = \underset{\text{Glycerin}}{C_3H_5(O.H)_3} + \underset{\text{Oleic acid}}{3C_{18}H_{34}O}$$

This change takes place in steam cylinders, when too high a percentage of fixed oil is used in the cylinder oil; the fatty acids thus liberated eat away the metal and form metallic soaps.

By heating olein with an alkali, *e.g.*, potash, the following change takes place:

$$\underset{\text{Olein}}{C_3H_5(C_{18}H_{33}O_2)_3} + \underset{\text{Potash}}{3KOH} = \underset{\text{Glycerin}}{C_3H_5(OH)_3} + \underset{\text{Potash oleate}}{3KC_{18}H_{33}O_2}$$

It will be seen that the fatty acid is not now liberated but has combined with the potash and formed a soap.

This action distinguishes fixed oils from mineral oils, which are not saponified when heated with an alkali but remain unchanged.

CHARACTERISTICS OF SOME FIXED OILS AND FATS

(See also Tables, pages 23 and 24)

Vegetable Oils and Fats. *Castor Oil* (*Nondrying*).—Castor oil is obtained from the seeds of the castor tree or shrub, which

grows in all tropical and subtropical countries. The kernel forms 80 per cent of the seed and yields about 50 per cent of its weight in oil. By cold pressing of the seeds, medicinal castor is produced. By hot pressing "first pressings" and "second pressings" are afterward produced. Castor oil may also be extracted by solvents. Crude castor oil is refined by steaming and filtration. When properly refined, castor oil keeps well and does not easily turn rancid.

Castor oil is liable to deposit a solid fat in very cold weather but congeals only at very low temperatures. It is nearly colorless or slightly greenish yellow; it has the highest specific gravity and viscosity of all fixed oils; it is soluble in alcohol but not in petroleum spirit when cold, nor does it mix to any large extent with mineral oils. It mixes with refined rosin oil in all proportions. It will absorb a maximum of about 12 per cent of pale, low-setting-point mineral lubricating oil, whereas mineral oil will not absorb much more than 3 per cent of castor oil.

All fixed oils, except castor, mix readily with mineral oils, and it is quite easy to make clear mixtures of castor oil and mineral oil in the presence of another fixed oil, such as lard oil or rape oil.

Castor oil is an excellent lubricant, possessing great oiliness. It is used for lubricating bearings subjected to great pressure, such as heavy-type marine engines, and is extensively used for airplane engines, particularly the rotary types, which cannot be lubricated satisfactorily with any oil other than pure medicinal castor. It is also used in the manufacture of soluble oils, in the manufacture of greases for pistons with India-rubber or leather fittings, as a preservative for rubber and leather belting, etc. The possibilities of castor oil as a lubricant appear to be far from exhausted. For example, little work has been done with blown castor oil, nor does there appear to be any satisfactory method developed for making miscible castor oil. One method is to heat castor oil for a few hours at 4 to 5 atmospheres pressure; this treatment changes its nature and makes it more miscible with mineral oil.

Treated with sulphuric acid, castor oil takes up 25 per cent of water and becomes "Turkey-red" oil used in preparing cotton fiber for dyeing.

Rape Oil (*Colza*) (*Semidrying*).—Rape oil is obtained either by expression or by extraction from rapeseed, grown chiefly in India and Russia. Crude rape is dark in color and contains

slimy impurities which are removed by treatment with sulphuric acid, followed by agitation with steam and hot water. If not sufficiently treated with acid, the slimy impurities choke the lubricating grooves; it is preferable to prolong the acid treatment and make sure of the elimination of the impurities, notwithstanding the development of a little extra free fatty acid.

Black Sea rape oil (Ravison rape) is expressed from seeds of the wild rape of the Black Sea district; it is inferior to ordinary rape oil, being about 10 per cent lower in viscosity and having a greater tendency to oxidize (more "drying").

Blown rape oil is rape oil that has been blown with air at a temperature rising during the process from 160 to 250°F. The oil is oxidized, increases greatly in specific gravity and viscosity, and develops free fatty acid. The specific gravity may be increased from 0.915 to as much as 0.985.

When rape oil is blown, the color darkens for about 3 hr.; then the oil becomes pale, but at the finish of the operation it darkens to a deep red; it gives off considerable odor, but the finished oil has no odor. The viscosity at first decreases correspondingly with the pale color, then increases, becoming 200 sec. Saybolt at 212°F. after 22 hr., 720 sec. Saybolt after 34 hr., etc.

Rape oil or blown rape oil is chiefly used in the manufacture of railway- and marine-engine oils, from 10 to 25 per cent being mixed with heavy-viscosity (preferably low-setting-point) mineral oils at a temperature of about 140°F. Rape oil is also used in the manufacture of soluble oils and as a quenching oil for steel.

Rape oil mixes in all proportions with mineral oil, but with blown rape oil there is a minimum percentage below which the blown rape will not mix with the mineral oil. This minimum percentage is less at lower temperatures, so that sometimes in cold weather the blown oil separates out. The blown oil also separates out, if oil containing blown rape is diluted sufficiently with mineral oil.

Cottonseed Oil (*Semidrying*).—Cottonseed oil is obtained by expression from cotton seed. On account of its drying properties, it should not be used for lubrication; it is, however, often used to adulterate olive oil, rape oil, or lard oil. Blown cottonseed oil is used as a substitute for blown rape oil in the manufacture of marine-engine oils but is not to be recommended. As a cutting oil it is used to give a high degree of "finish."

Linseed Oil (Drying).—Linseed oil is obtained from the seed of flax, is pale yellow in color, and is the best known of the drying oils. It cannot be used as a lubricant.

Olive Oil (Nondrying).—Olive oil is obtained by expression from the fruit of the olive tree. Fine olive oils are pressed cold and are used as salad oils as well as for lubrication. Olive oils from the second pressing (hot) are used for lubrication but are inferior to cold-pressed olive oil; they are more inclined to "dry," contain a rather high percentage of free fatty acid, and easily become rancid. Olive oils have now practically gone out of use for lubrication, having been displaced by mineral oils or mixtures of such oils with rape oil.

Olive oil is largely used as wool oil in the high-class woollen industry; it is unsurpassed for this purpose, lubricating the woollen fibers during manufacture and being completely scoured out of the yarn when completed. It is used for lubricating high-quality cloth looms or finishing machines, as, if it gets on to the cloth, the stains disappear entirely in the scouring process.

Coconut Oil (Nondrying).—Coconut oil is produced from coconuts, the fruits of a certain kind of palm tree. The kernels are cut up and dried in the sun, producing the so-called "copra" from which coconut oil is obtained by expression.

Coconut oil is fluid in tropical climates and solid in colder climates, the melting point being 70 to 80°F. By cold pressing a fluid, coconut olein, is obtained which is used for lubricating purposes; the solid portion is used as an edible fat.

Coconut olein is used to the extent of from 3 to 10 per cent in the manufacture of oils for internal-combustion engines.

Palm Oil, Palm-kernel Oil (Nondrying).—Palm oil and palm-kernel oil are obtained from the fruit of the African oil palm. The palm oil is produced from the fleshy layer, or pericarp, surrounding the hard woody shell, within which is the seed kernel. The palm-kernel oil is produced from the kernels and is quite different from palm oil; it closely resembles coconut oil but usually contains a large proportion of free fatty acid and is not used for lubrication.

Palm oil varies in color from yellow to deep red; the odor is pleasant; the melting point ranges from 80 to 110°F., the higher values corresponding with high percentages of free fatty acid, which are present to the extent of 10 to 40 per cent or even more.

Palm oil is used in the manufacture of railway lubricating greases.

Peanut Oil, Also Called Earthnut Oil, Groundnut Oil, Arachis Oil (Nondrying).—This oil is obtained from the nuts of a creeping plant called *Arachis hypogœa.* It is pale greenish yellow in color, of a nutty flavor and odor, but is now made nearly colorless and tasteless for edible purposes. It contains about 5 per cent of free fatty acid and is a nondrying oil. Peanut oil is used in the same manner as coconut olein is the manufacture of oils for internal-combustion engines.

Mustard-seed Oil.—Mustard-seed oil is said to have lubricating properties similar to those of castor oil, but it does not appear to have been much used as yet for lubrication.

Rosin Oil (Semidrying).—Rosin oil is produced by destructive distillation of colophony (common rosin). The first products distilling over are rosin spirits. The rosin oil distills over above 300°C. (572°F.) and may amount to 85 per cent of the total products. The residue in the still is rosin pitch or, if the distillation is carried to dryness, coke.

Crude rosin oil is a brown, viscous liquid with a strong blue or violet fluorescence. By heating to 150°C. for three or four hours the fluorescence changes to green, and it loses from 1 to 5 per cent of its more volatile constituents. It contains a considerable percentage of rosin acids.

Pale rosin oils can be produced by refining the crude rosin oil. The bloom can be removed by sun bleaching in shallow vessels or by treatment with nitronaphthalene, hydrogen peroxide, etc.

The specific gravity ranges from 0.96 to 1.01.

Rosin oil is not used as a lubricant in the ordinary way, but both rosin and rosin oil are successfully used in the manufacture of soluble oils, belt dressings, etc. It is also used in the manufacture of low-quality lubricating greases.

Animal Oils and Fats. *Tallow (Nondrying).*—Beef tallow is obtained from cattle; mutton tallow, from sheep and goats. In rendering tallow for lubrication, it is important to use only fresh fat, which has not become decomposed, and to remove by settling and straining all water and membrane.

Tallow from 60 to 80°F. is a mixture of solid and fluid fats. When used for lubrication it should preferably not contain more than 4 per cent of free fatty acid in terms of oleic acid.

Beef tallow is less inclined to become rancid than mutton tallow.

Tallow is used in the manufacture of white tallow greases, also in most other lubricating greases to form the saponified base which "holds" the lubricating oil in the grease. Unrendered tallow—suet—is sometimes used for lubricating badly worn, open-type bearings.

Tallow Oil (*Nondrying*).—If tallow is subjected to pressure, the liquid portion can be separated out and is known as tallow oil. Acidless tallow oil is carefully made tallow oil and is used chiefly in the manufacture of steam cylinder oils, the admixture of tallow oil being from 3 to 15 per cent. It is also used in the manufacture of cutting oils. It should have a low content of fatty acid and a clean sweet odor; it should be colorless or pale yellow and free from suspended matter.

Lard Oil (*Nondrying*).—Lard oil is a fluid oil expressed from pig's fat. Winter-pressed lard oil has a lower setting point than summer-pressed lard oil. The setting point depends entirely upon the temperature at which the oil has been pressed; it may range from 32 to 60°F.

Prime lard oil is nearly colorless or pale yellow.

Tinged lard oil is a second-quality lard oil, being more or less colored (yellow to brownish red) and containing a high percentage of free fatty acid—from 8 to 15 per cent or more.

The best grades of lard oil are used in the manufacture of cutting oils (5 to 100 per cent lard oil), in the manufacture of internal-combustion engine oils (3 to 10 per cent lard oil), also in the manufacture of stainless oils. Tinged lard oil is nearly always used instead of prime lard oil in making cutting oils, but not in a greater proportion than 15 to 25 per cent on account of its bad odor and a gumming tendency greater than that of prime lard.

Neat's-foot Oil (*Nondrying*).—Neat's-foot oil is obtained by boiling the hooves and bones of cattle in water and skimming off the oil from the surface. When the oil is chilled and pressed, a low-setting-point neat's-foot oil is produced, which is much used for lubrication of watches and scientific instruments; it is used for lubricating the air-operated engines in torpedoes, also for lubricating lacemaking machinery on account of its clinging and stainless properties. The high price of neat's-foot oil has confined its use as a lubricant to such special purposes.

Neat's-foot oil in its general properties resembles lard oil and is used largely for treating leather.

Sperm Oil (Nondrying).—Southern sperm is obtained from the head or blubber of the sperm-whale, which is generally found in tropical or temperate seas. A large cavity in the head of the whale is filled with crystalline matter called "spermaceti." Arctic sperm is obtained from the blubber of the bottlenose whale, which is found in the northern seas—hence the name.

The crude sperm oil is cooled, so that most of the spermaceti separates out, then pressed. The spermaceti is used for making candles.

Sperm oil has only a slight tendency to oxidize, a low setting point, and the lowest viscosity and specific gravity of all fixed oils. It is a valuable lubricant for high-speed spindles in textile mills, being generally used mixed with low-viscosity mineral oils (5 to 25 per cent sperm).

Whale Oil (Semidrying).—Whale oil is obtained from the blubber of the Greenland and other whales. The specific gravity of whale oil is much higher than that of sperm oil. Whale oil has marked drying properties, but the pale grades are used successfully as lubricants when mixed in small proportions (5 to 10 per cent) with mineral spindle oils for textile purposes or as cutting oils. Dark whale oils are lower in quality and cannot be used for lubrication but are excellent as tempering or quenching oils used in the manufacture of tools, guns, case-hardened materials, etc.

Seal oil is similar to whale oil and is obtained from the blubber of seals.

Porpoise Oil, Dolphin Oil, and Melon Oil (Nondrying).—These oils, which are very similar, are obtained from the soft fat of the head and jaw of the porpoise and the dolphin.

Melon oil is made from a melon-shaped lump of fat in the head of the dolphin; the crude oils, obtained in the usual way, are chilled and pressed to remove solid fat. These oils are used, particularly in the United States, for lubricating watches and other delicate mechanisms and command a high price.

Menhaden, Cod, or Other Fish Oils (Semidrying).—Menhaden, cod, or other fish oils are obtained by boiling fish in large pans with steam; after standing some time the oil rises to the surface

and can be skimmed off. The color varies according to the freshness of the fish and the length of boiling.

Fish oils are chiefly used in the leather industry, but blown cod oil, blown in a manner similar to that used for blown rape oil and to similar viscosities, has given fair satisfaction in the manufacture of marine-engine oils. Fish oils have also been used as quenching and tempering oils.

Characteristics of Fixed Oils and Fats

	Specific gravity	Setting point, degrees Fahrenheit	Open flash point, degrees Fahrenheit	Iodine value	Saponification value	Free fatty acid, per cent	Drying character
Castor oil	0.960 to 0.966	0 to 10	530 to 560	80 to 90	176 to 186	0.1 to 6	Non-
Rape oil	0.913 to 0.916	12 to 26	530 to 560	96 to 108	170 to 176	0.3 to 3	Semi-
Ravison rape	0.918 to 0.922	....	....	108 to 120	178 to 179	2 to 6	Semi-
Blown rape	0.960 to 0.985	....	....	....	....	....	Semi-
Cottonseed oil	0.921 to 0.926	32	560 to 625	100 to 120	192 to 195	....	Semi-
Linseed oil	0.931 to 0.936	−15 to 10	550	170 to 200	192 to 195	0.4 to 4	Drying
Olive oil	0.915 to 0.918	20 to 50	475 to 600	80 to 90	185 to 196	3 to 20	Non-
Coconut olein	0.925 to 0.930	40 to 70	530	8 to 9	250 to 260	2 to 20	Non-
Palm oil	0.922 to 0.925	80 to 110	450	50 to 56	196 to 202	10 to 60	Non-
Peanut oil	0.918 to 0.925	27 to 37	540 to 620	90 to 102	187 to 191	1 to 5	Non-
Rosin oil	0.960 tol.01	....	360	25 to 115	70 to 80	0 to 35	Non-to semi-
Tallow, beef, or mutton	0.935 to 0.950	100 to 125	550 to 590	34 to 48	195	2 to 10	Non-
Tallow oil	0.913 to 0.918	32 to 40	540 to 600	55 to 60	195	1 to 5	Non-
Lard oil	0.914 to 0.918	32 to 60	500 to 600	65 to 75	195	3 to 25	Non-
Neat's-foot oil	0.914 to 0.917	0 to 40	470 to 580	65 to 75	195	0.2 to 25	Non-
Sperm oil	0.878 to 0.882	32	505	80 to 94	120 to 140	0.5 to 3	Non-
Whale oil	0.924 to 0.925	40 to 50	475	110 to 130	187 to 197	2 to 10	Semi-
Porpoise oil	0.916 to 0.927	....	....	22 to 48	....	....	Non-
Menhaden oil	0.930 to 0.933	20 to 25	530	140 to 170	*191	3 to 6	Semi-
Cod oil, fish oil	0.921 to 0.928	20	470	145 to 170	*189	1 to 15	Semi-
Wool grease	0.944 to 0.960	100 to 130	450	15 to 30	*100	50 to 60	Non-

* Single values only.

Wool Grease.—Wool grease is obtained in the process of wool washing; the alkaline scouring liquors containing the wool grease are run into settling tanks; the fatty matter accumulating on the surface is collected and drained in filter bags. The scouring liquors may also be treated with sulphuric acid in conjunction with injection of live steam; the acid separates the fatty matter,

and three distinct layers are formed—greasy matter on the top, water and soda in the middle, and earthy matter at the bottom.

The extracted grease is dirty and contains water; the water is removed by cold and hot pressing, followed by strong sulphuric acid treatment. The wool grease thus prepared is known to the trade as "Yorkshire grease" and is used in the manufacture of rolling-mill, railway, and colliery greases.

VISCOSITIES OF SOME FIXED OILS AND FATS

Oil or fat	Saybolt seconds			Redwood seconds		Engler number		Absolute viscosity, centipoises		
	100°F.	130°F.	212°F.	70°F.	140°F.	20°C.	50°C.	40°C.	50°C.	60°C.
Castor oil	1200	425	95	2700	265	100	15	220	107	67
Rape oil	250	135	57	345	89	12	4.6	44	31	21
Tallow, beef, or mutton	....	...	53	....	86					
Lard oil, neat's-foot oil; Olive oil, peanut oil	210	115	51	330	85	11.5	3.9	37	28	20
Cottonseed oil	170	95	50	250	67	9.3	3.1	30	22	16
Coconut oil, whale oil	145	81	43	210	55	7.8	2.7	25	18	13
Sperm oil	100	58	38	125	34	4.5	1.8	17	12	8

On the Continent a process of wool cleansing by means of solvents (ether or carbon bisulphide) is often employed; the solvents are afterward recovered by distillation, and the wool grease remains behind. Such wool grease is usually distilled with superheated steam and produces wool olein and wool stearin, etc. One use of wool olein is in the manufacture of wool oils.

CHAPTER III

SEMISOLID LUBRICANTS

Semisolid lubricants are lubricants that do not flow at ordinary room temperatures. Animal or vegetable fats, such as tallow or palm oil, or poor cold-test cylinder stock may be classified as semisolid lubricants. Most semisolid lubricants are, however, made from mineral oils and saponified fats or fixed oils and may be divided into two main groups, *i.e.*, cup greases and solidified oils or fats.

Cup greases are boiled greases and consist of 80 to 90 per cent of mineral oil mixed homogeneously with 10 to 20 per cent of saponified fat, preferably clarified beef tallow. The tallow is mixed with limewater and heated in a steam-jacketed kettle (60 to 90 lb. steam pressure) for 3 to 4 hr. until the *base* for the grease is completely formed. The mineral oil is gradually (5 to 6 hr.) mixed with the base until the right consistency of the grease has been obtained, the mixture being constantly agitated mechanically or by compressed air.

The grease is then run out during the next couple of hours, during which the consistency becomes gradually softer owing to the agitation, notwithstanding that the speed of the stirrers is reduced toward the finish. Some manufacturers run the grease out of the boiling kettle into a grinding mill, in which all lumpy matter and impurities are reduced, and the grease made of a uniform consistency (the more the grease is kneaded the softer it becomes).

Grinding the impurities fine does not, however, remove them; it is better to strain the grease when it leaves the kettle. This is best done by forcing the grease, when hot and fluid, under great pressure through fine layers of gauze. The gauze retains all the impurities, so that the grease is perfectly clean when filled into the packages. It is surprising to see the amount of impurities that can be retained in this way from grease that one might consider practically clean.

The ideal amount of grease made in one batch is 20 to 25 bbl.

Cup greases should be free from fillers, such as chalk, china clay, gypsum (sulphate of calcium), barytes (sulphate of barium), asbestos, talc, wax, etc.; they should be free from uncombined lime, gritty impurities, rosin oil, rosin or resinates, mineral or fatty acids, alkalies, or other deleterious impurities; the yield of ash should be less than 2 per cent for a medium grease and less than 3 per cent for a hard grease; the content of water should be less than 2 per cent.

The melting points of ordinary cup greases range from 75 to 95°C., being higher for the harder consistency greases than for the softer greases.

The consistencies of greases range from very soft to very hard and are frequently indicated by numbers, as follows:

No. 1	No. 2	No. 3	No. 4	No. 5
Very soft	Soft	Medium	Hard	Very hard

The softer the grease the more oil does it contain.

The mineral oils used for making cup greases are pale mineral oils (pale to give the grease a light color). Red oils might quite well be used; the drawback is that they do not give the grease such a nice appearance as the pale oils. The viscosities of the mineral oils used range from 150 to 1200 sec. at 70°F.

Graphite lubricating grease is cup grease that has been mixed with from 5 to 20 per cent of amorphous or flake graphite.

Cold-neck greases are black lime greases made with black heavy-viscosity oils and are used for lubricating "cold" rolling-mill necks in steelworks.

Fiber greases are of a "fibrous" nature but contain no fibers of any kind. They are usually made by saponifying a fixed oil with caustic potash or caustic soda instead of lime and a little water. After saponification the water is boiled out, and the mineral oil is worked in. Fiber greases of good quality can be melted and cooled again without altering their consistency.

Some fiber greases have very high melting points, ranging from 145 to 260°C.

Solidified oils or fats are made in a manner similar to that used for cup greases but are made cold and with carbonate of soda or caustic soda as the saponifying agent in place of limewater. These greases may be made in small quantities, as it is a question

only of mixing the right proportions of the various ingredients together, cold or at fairly low temperature, and stirring the mixture till it sets. It is obvious that the ingredients cannot be so perfectly mixed and combined as with cup greases, which are boiled; the result is that certain parts of the grease will often contain excess soda, which is detrimental to good lubrication.

Many so-called soap-thickened oils are a kind of solidified oil, various soaps being added to a mineral oil. Sometimes special "thickeners" are sold for the purpose of increasing the viscosity of mineral oils; *e.g.*, aluminum soap is used, consisting of 20 per cent aluminum oleate or palmitate and 80 per cent mineral oil, in which the soap is dissolved. Mineral oils thickened with aluminum soap have a peculiar nonhomogeneous nature; the viscosity is unstable, and the oil is of a slimy nature, forming threads when dropping. In contact with water and steam the aluminum soap is precipitated and clogs the machinery.

White greases are usually made from aninal fat and a small amount of mineral oil, solidified by soap. The melting points are lower than the melting points of cup grease, ranging from 45 to 70°C.

Certain white greases contain finely pulverized mica and are sold under the name of mica greases.

Railway-wagon Grease.—The yellow grease used in the axle boxes of railway wagons is usually composed of tallow, palm oil, soda soap, and water.

According to a number of formulas quoted by Archbutt, the specifications are approximately as follows:

	Per Cent
Saponifiable oils.....	30 to 45, occasionally partly replaced by mineral oil
Anhydrous soap.....	10 to 30
Water..............	40 to 60
Insoluble matter.....	0.02 to 2.8

Usually 3 to 5 per cent more water is used in the winter greases than in the summer ones.

A good wagon grease should melt at about 40°C. without separating; cup greases are unsuitable for railway wagons, as they have too high melting points, and when continuously exposed to high temperature in the axle boxes the oil separates out, leaving the soap behind.

Rosin grease is made by stirring together rosin oil, slaked lime, and usually black mineral oil or neutral coal-tar oil.

The rosin acids present in the rosin oil combine with the lime, forming a soap, which solidifies the mixture of the various oils. Water to the extent of up to 20 per cent is sometimes present in rosin greases.

Rosin greases are used to lubricate rough machinery in collieries and steelworks.

Hot-neck greases are very hard greases made from heavy residues such as wool pitch, stearine pitch, petroleum pitch, heavy asphaltic-base petroleum lubricating oils, thickened with soap or rosin grease and containing finely pulverized talc or graphite. Hot-neck greases are used for lubricating "hot" rolling-mill necks in tinplate works and steelworks.

Pinion greases are closely related to hot-neck greases; they frequently contain pine-tar oil and are very sticky and adhesive.

Special Greases.—*Gear grease* can be made by mixing a heavy-viscosity mineral oil with fiber grease or with paraffin wax. Such mixtures are reasonably stable when used in the gearboxes of motor cars.

Solidified oils are not satisfactory as gear greases, nor are those cup greases the bases for which have been made from rape oil or cottonseed oil. Such greases have too high melting points, separate under heat, and the soap that is left cakes and carbonizes. Cup greases made from a tallow-lime base give reasonable satisfaction but are also too high in melting point and inclined to cake.

Yarn grease is a mixture of ordinary cup grease or fiber grease and cotton waste or woollen yarn, preferably the latter. The strands should not be too long—1½ to 2½ in. is a suitable length; longer strands get entangled, and it becomes difficult to divide the grease when applying it to bearings.

Black floating grease is made by mixing dark heavy-viscosity lubricating oils with powdered talc, in about even proportions; this grease is still used in some collieries as a car grease. It is low in price and causes great friction and wear, but the bearings rarely seize or get scored.

Petroleum grease is either a petroleum jelly (see page 9) or a mixture of petroleum jelly with thin mineral oil; these greases have low melting points and little lubricating value, but they

contain no moisture and are for that reason recommended by several makers of small ball and roller bearings.

Scented Grease.—Many greases—cup grease, solidified oil, etc.—particularly when made from rancid fats or fatty oils, are scented with oil of citronella or with nitrobenzene to cover up the bad odor. Such scenting should be discouraged, as it is difficult to know whether a scented grease is of good or bad quality.

CHAPTER IV

SOLID LUBRICANTS

Several kinds of solid materials, such as graphite, talc, soapstone, mica, flowers of sulphur, and white lead, are used for lubricating purposes. Some of these solid lubricants, as flake graphite or mica, possess a tough, flaky, foliated structure which enables them to resist pressure without disintegration. Others, such as amorphous graphite or flowers of sulphur, are easily crushed into a fine powder when exposed to pressure.

Again, solid lubricants may be so finely divided as to enable them to be suspended in colloidal form in a liquid carrier. The colloidal graphite preparations aquadag and oildag, made by Acheson's process, are examples of such lubricants, being diffusions of colloidal graphite in water and oil, respectively.

CHARACTERISTICS OF SOLID LUBRICANTS

Graphite.—Graphite is the most important of all solid lubricants. It is not attacked by acids or alkalies or affected by high or low temperatures.

Graphite is also called "black lead" or "plumbago," but these names are slowly going out of use.

Natural Graphite.—The greater part of the world's supplies of natural graphite comes from Austria, Ceylon, Italy, Bavaria, Madagascar, the United States, Canada, Mexico, Japan, Siberia, and England.

Natural graphite is found in two forms—flake graphite and amorphous graphite—the former is of a tough, flakey structure and has a pronounced luster, whereas the amorphous graphite has no such luster.

Natural graphite, as it is obtained from the graphite mines, contains some impurities, chiefly silica, alumina, and ferric oxide.

Most of the natural graphite employed for lubricating purposes is of the flake variety. The flake formation is retained even if it be ground into a fine powder. It is manufactured in several degrees of fineness.

Flake graphite may be used either dry or in admixture with semisolid lubricants. It cannot be used mixed with oil in ordinary lubricators or lubricating systems, because of its high specific gravity (2.2), which causes it to separate out and choke lubricators, oil pipes, and oil grooves.

Artificial Graphite.—Amorphous graphite is produced artificially by Acheson in the electrical furnace. He is able by his process to produce graphite of a soft, unctuous, noncoalescing nature and almost chemically pure.

The varieties produced for lubricating purposes are guaranteed to contain 99 per cent of pure carbon but usually contain more. In one variety of graphite—No. 1340—98 per cent of the graphite particles are less than $\frac{1}{338}$ in. in diameter. From this or similar graphite Acheson produces what he calls deflocculated graphite by kneading it for a long time with water in the presence of a vegetable extract, such as tannic acid. The graphite particles in this process disintegrate into particles one thousand times less in diameter; in fact, Acheson estimates that each particle of the "1340" graphite becomes divided into 700,000 particles, a smallness of size bordering on the molecular. The graphite becomes diffused in the water in colloidal form, and each particle, being protected by an envelope of organic colloidal matter, remains in suspension for an indefinite time in the water.

The graphite exists in the form of hexagonal tilelike particles which dispose themselves with their broad faces to the sliding surfaces, the particles on opposing surfaces readily sliding over one another with little friction.

Acheson manufactures the colloidal solution of graphite in water in the form of a concentrated paste under the name of "aquadag." It may be diluted by the addition of pure water to the required strength without the graphite's separating out. By a further process the concentrated aquadag is mixed and kneaded with mineral lubricating oil until all the water is replaced by oil; this product is called "oildag" and may be diluted with good-quality neutral mineral oil without any appreciable separation of the graphite, without "flocculation," as Acheson calls it.

"Glydag" is a concentrated preparation containing 10 per cent electric furnace graphite (by weight) colloidally dispersed in glycerin, a valuable low-temperature lubricant. For certain purposes, a mixture of aquadag and glydag may be preferable.

In Germany, colloidal solutions of graphite have been produced commercially by E. de Haen, similar to aquadag and oildag, the corresponding names being hydrosol (corresponding to aquadag) and oleosol or kollag (corresponding to oildag). According to Holde,[1] in both forms of colloidal graphites there are graphite particles of a size from 1 to 6μ, but the majority are submicrons less than 1μ in size (1μ equals 0.001 mm.) which are not easily separated out by centrifuging, whereas the larger particles from 1 to 6μ are easily separated out in this manner.

Colloidal solid lubricants may be produced from materials other than graphite. It will appear that some successful attempts have been made with talc and mica.

Talc.—*Talc* consists of hydrogen magnesium silicate ($H_2Mg_3Si_4O_{12}$) and occurs as foliated or scaly compact masses. Its specific gravity ranges from 2.6 to 2.8.

The term *steatite* is restricted to the compact massive varieties of talc.

Soapstone is an impure form of steatite.

French chalk is talc or steatite in powder form.

Talc scales feel greasy or soapy, possess a perfect micaceous cleavage, have a pearly to silvery luster, and are flexible but not elastic, thus differing from mica.

Talc is very soft and can readily be scratched with the fingernail; it is selected as No. 1 in Mohs's hardness scale, although the harder varieties of talc may have a hardness of 2.5 to 4. The color of talc varies from silvery white for the best and softest varieties to grayish or greenish for the harder steatite varieties.

Talc resists acids and alkalies and also heat (no water being lost below a red heat) and cold. It is obtained chiefly from the United States but is found also in many other countries such as England (Cornwall), Bavaria, France, Italy, Austria, and India.

Mica.—The name "mica" is applied to a group of minerals characterized by the facility with which they split into thin lamina which are flexible and more or less elastic. The hardness of the micas is between 2 and 3, while their specific gravity ranges from 2.7 to 3.1.

The chemical composition is subject to considerable variations in different species—broadly speaking, there is a group of potash

[1] *Zeitschrift für Elektrochemie* 23/16, 1917.

micas, generally pale in color; and a group of magnesium or ferric magnesia micas, usually dark in color.

All the micas are complex silicates containing aluminum and potassium generally associated with magnesium but rarely with calcium.

Water is always present, and many micas contain fluorine.

Mica is prepared for the market by splitting the blocks of rough mica into plates which are cut into the required patterns by means of shears.

The refuse mica when finely ground forms the material used for lubricating purposes. The small particles of mica still retain their thin lamellar structure.

Flowers of Sulphur.—Flowers of sulphur is not used much for lubricating purposes but is used to some extent for curing hot bearings. It is a fine powder consisting of pure sulphur largely in the form of minute crystals. The specific gravity is approximately 2.

White Lead.—White lead is used to some small extent for curing hot bearings. It is an extremely fine powder consisting chemically of basic carbonate of lead and generally said to have the following formula: $2PbCO_3 \cdot Pb(OH)_2$.

CHAPTER V

TESTING LUBRICANTS

In the early days, when mineral lubricating oils were nearly all made from Pennsylvania or Russian crudes, only a few varieties were manufactured, and simple physical and chemical tests sufficed to identify the oil. This state of affairs no longer exists; lubricating oils are now made from a great variety of crudes, and great experience is required to judge the merits of an oil on the basis of a laboratory analysis.

The selection of an oil for certain engines or machinery requires many years of experience in comparing and testing different lubricants under actual running conditions. Laboratory tests and investigations alone are of no avail, as chemists usually have no engineering experience; on the other hand, lubricating engineers cannot develop their experience and judgment without the very best chemical assistance; in fact, it is only by coordinating field engineering experience with careful laboratory investigations that it is possible to accumulate the kind of knowledge that is required to enable one to give sound recommendations as to the grades of lubricants that should be selected for a given purpose, as well as the best methods of application and use.

It is a well-known fact that the vast majority of oil firms operate on the principle of getting samples of oils in use, analyzing these samples more or less roughly, and then offering oils more or less similar in character. As the customer in most cases does not trouble much about the quality of the oils, as long as the "price is right" and as long as nothing serious happens to his machinery, the prevailing standard of lubrication is usually exceedingly low. The author, who for many years has been in charge of a large staff of lubrication engineers, can testify that very few works exist where a lubricating engineer, after a thorough works inspection, cannot point out means by which great economies can be affected from the point of view of saving in power (with all its attendant benefits), saving in lubricants,

greater safety of operation, etc., all due to better lubricants or better methods of handling them from the moment they are received at the stores till the moment the last drop has been consumed in the works.

It should not be necessary for a capable lubricating engineer to have samples of the lubricants in use in order to recommend the correct grades of his firm's products. His general lubrication knowledge of engines and machinery and his observations during the inspection ought to be sufficient for that purpose. But if he is to give an accurate estimate of the possible saving in power or consumption to be obtained by introducing better or more suitable lubricants, then an analysis of the lubricants in use and of the consumption in all departments is required.

Speaking generally, in order to satisfy certain lubricating requirements, the lubricant

1. Must possess sufficient viscosity and lubricating power—oiliness—to suit the *mechanical conditions* and conditions of *speed, pressure*, and *temperature.*

Too little oiliness means excessive wear and friction; too high a viscosity means loss of power in overcoming unnecessary fluid friction.

2. Must suit the *lubricating system.*

When, for example, the oil pipes are exposed to cold, a lower cold-test oil is required than when the oil pipes are not so exposed.

3. Must be of such a nature that it will not *produce deposits* during use exposed to the *influence of air, gas, water*, or *impurities* with which the oil may come into more or less intimate contact while performing its duty.

The particular physical and chemical tests needed will depend on the class of work for which the oil is to be used and will become more apparent from the chapters in this book devoted to particular types or sections of engines and machinery.

In the manufacture of lubricating oils it is of the greatest importance that the various grades be kept always as closely as possible to certain predetermined standards. Engineers who have to do with the practical application of oils fully appreciate this point. For example, a drop-feed lubricator on a bearing is set to give a certain feed of oil which has been found satisfactory; a new supply of oil is received of a lower or higher viscosity than the former supply; the feed of the lubricator will then be either

greater, which means oil wasted, or smaller, with the result that the bearing may run warm.

Physical and chemical tests of lubricants are therefore of great value to the oil manufacturer for controlling the manufacture of lubricating oils during the distillation, refining, and compounding operations, up to the point when the oil is placed in the stores ready for shipment. Physical and chemical tests are also extremely valuable for the purpose of identifying an oil or for detecting adulterations.

In the following chapters the author will endeavor to show the importance of physical, chemical, and mechanical testing methods, but with the exception of one or two, which he feels may not be generally known, it is not proposed to describe the apparatus.

The author has divided "Testing Lubricants" into two sections, *viz.*, "Physical and Chemical Tests" and "Mechanical Means of Testing Lubricants," the latter section dealing briefly with friction testing machines and works methods of carrying out comparative tests on engines and machinery.

PHYSICAL AND CHEMICAL TESTS

Physical Tests:

Density and Specific Gravity.
Coefficient of Expansion.
Flash Point and Fire Point.
Volatility—Loss by Evaporation.
Distillation.
Dilution Test.
Specific Heat.
Cold Test, Pour Test, and Cloud Test.
Melting Point.
Color and Fluorescence.
Viscosity of Oils.
Viscosity of Semisolid Lubricants.
Capillarity.
Emulsification.
Surface Tension.

Chemical Tests:

Acidity.
Saponification Value.
Iodine Value.
Oxidation and Gumming.

Ash.
Carbon Residue.
Asphalt and Tar.
Oiliness.
Impurities (Dirt, Glue, Water).

PHYSICAL TESTS

Density and Specific Gravity.—The specific gravity of a substance is the weight compared with that of an equal volume of water as unity.

In the United States and Great Britain the specific gravity is the 60°F./60°F. value, which means that the specific gravity is measured at 60°F. as compared with water at 60°F. as unity.

On the Continent the 15°C./4°C. value is generally used, which means that the specific gravity is measured at 15°C. and compared with water at 4°C. as unity, this being the temperature at which water has its maximum density.

Density in the c.g.s. system (metric system) means the weight of 1 ml. (= cubic centimeter) of a substance as compared with the weight of 1 ml. of water at 4°C. The specific gravity 15°C./4°C. therefore represents in the metric system the density of the substance at 15°C. The 15°C./4°C. specific gravity is obviously less than the 60°F./60°F. value, but as the coefficient of expansion of water is exceedingly small, the difference in value is only slight.

As indicated in the table (page 24) the specific gravities of the various fixed oils do not differ much from one another, whereas the specific gravities of mineral oils differ considerably, depending not only upon the crude itself but also upon the method of distillation and refining.

For oils made from similar crudes by similar methods the specific gravity increases with the viscosity. Speaking generally, nonparaffinic-base oils have higher specific gravities than paraffin-base oils, the difference for similar-viscosity oils being from 0.020 to 0.040. Oils treated by acid and cracked oils have higher speoific gravities than oils treated by filtration and uncracked oils, respectively. Coal-tar oils and rosin oils have specific gravities in the neighborhood of 1.0, coal-tar oils always being above 1.0.

The specific gravity is therefore important, since when couped with other tests it assists in identifying an oil as coming from a

certain type of crude, etc. The specific gravity has, however, no *direct* bearing on the lubricating value of a lubricant.

The specific gravity may be determined by pyknometer, hydrometer, or the Westphal balance. The pyknometer method (specific-gravity bottle or the Sprengel tube) is applicable to all liquids and is the most accurate method for lubricating oils. The hydrometer and the Westphal balance are less accurate, but both methods are capable of giving sufficiently accurate results for commercial purposes and are handier to use than the pyknometer, especially the hydrometer.

The Baumé gravity is measured by a hydrometer and is much used in the United States. The conversion of gravity from degrees Baumé to specific gravity can be carried out according to the formula

$$\text{Specific gravity} = \frac{140}{{}^\circ\text{Bé.} + 130}$$

As 1 l. of water weighs 1 kg., the weight of 1 l. of oil in kilograms is expressed by its specific gravity. As 1 imperial gallon weighs 10 lb., the weight of 1 imperial gallon of oil in pounds is equal to ten times its specific gravity. This rule cannot be applied to American gallons, 1 American wine gallon equalling $\frac{5}{6}$ imperial gallon.

The Twaddell gravity scale is sometimes used for liquids heavier than water, such as coal-tar products, caustic potash, sulphuric acid, and other chemicals. To convert degrees Twaddell to specific gravity use the following formula:

$$\text{Specific gravity} = \frac{1{,}000 + (5 \times \text{degrees Twaddell})}{1{,}000}$$

Coefficient of Expansion.—The coefficient of expansion is the expansion or contraction per unit volume following a change in temperature of 1°.

The coefficient of expansion is the same for all mineral oils of the same specific gravity and can be taken near enough for practical purposes as being:[1]

[1] U. S. Bureau of Standard *Technologic Paper* 77: Density and Thermal Expansion of American Petroleum Oils.

Fluid	Specific gravity	Coefficient of expansion	
		Per °F.	Per °C.
For gasoline	0.620 to 0.760	0.00050	0.00090
For kerosene	0.780 to 0.830	0.00040	0.00072
For lubricating oils, including fixed oils	0.850 to 0.970	0.00036	0.00065

The density of an oil will vary, with a certain change in temperature, an amount equal to the coefficient of expansion multiplied by the number of degrees that the temperature has changed.

To know the value of the coefficient of expansion is therefore useful for converting the gravity measured at a temperature different from the standard temperature (which is 60°F. in the United Kingdom and United States) to the gravity at the standard temperature. It is also useful for measuring the stock of oil in an oil-storage tank, as the volume must always be corrected to represent volume at a standard temperature.

In correcting the specific gravity for variation in temperature, the correction coefficient is not, as is often assumed, the coefficient of expansion but the product of the latter and the specific gravity taken at the temperature of the oil. It may be useful to show how the true correction is calculated.

The change in volume due to change of temperature is expressed in the fundamental formula

$$V_T = V_{60}[1 + C(T - 60)]$$

where V_T = volume of a certain weight of oil at the temperature T.

V_{60} = volume of the same weight of oil at 60°F.

C = coefficient of expansion.

The weight of the oil equals the volume multiplied by the specific gravity, so that

$$V_{60} \times S_{60} = V_T \times S_T$$

or

$$V_T = \frac{V_{60} \times S_{60}}{S_T}$$

where S_{60}, S_T = specific gravities of the oil at 60 and T°F., respectively.

We can now rewrite our formula as follows:

$$\frac{V_{60} \times S_{60}}{S_T} = V_{60}[1 + C(T - 60)]$$

or

$$S_{60} = S_T + S_T \times C \times (T - 60)$$

In other words, the specific gravity at 60°F. equals the specific gravity at T°F. plus the product of (1) the difference in temperature between T and 60, (2) the coefficient of expansion, and (3) the specific gravity at T°F.

Flash Point and Fire Point.—The *flash point* of an oil is the temperature at which the oil gives off sufficient vapors to ignite momentarily when exposed to a flame or spark. The oil must be heated at a uniform rate and not too rapidly, as that would give too low a flash point.

The *open flash point* is the flash point determined when heating the oil in an open cup.

The *closed flash point* is the flash point determined when heating the oil in a closed vessel, which rather prevents the vapors from escaping, so that the closed flash point is always lower than the open flash point. The difference is greater the higher the flash point of the oil.

The *fire point* of an oil is the temperature at which the oil gives off sufficient vapors to ignite and continue to burn when exposed to a flame or spark. The test is made with the same apparatus as is used for determining the flash point, the oil being heated beyond the flash point until the fire point is reached.

No oil is used for lubricating purposes with an open flash point less than 300°F. The open flash points of all lubricating oils, including fixed oils, range from 300 to 650°F. The closed flash point of a lubricating oil is recorded only for special oils, such as air-compressor oils, and transformer oils.

The apparatus employed for testing flash and fire points varies for different countries. Thermometers are usually standardized with the bulb and stem at the same temperature. As the stem of the thermometer when determining flash and fire points is not exposed to high temperature, the results should be corrected by adding to the thermometer readings the following degrees Fahrenheit:

275—300— 5	425—450—13
300—325— 6	450—500—16
325—350— 7	500—550—20
350—375— 8	550—600—23
375—400—10	600—650—27
400—425—11	650—700—30

Pensky-Martens apparatus is more widely used for lubricating oils in many countries than any other apparatus.

The *Gray* instrument is an adaptation of the Pensky-Martens apparatus, and the two instruments give identical readings.

The *Abel* instrument is used principally for taking closed flash points of spirits and illuminating oils.

Fixed oils do not evaporate until they begin to decompose, whereas mineral oils start to evaporate long before their flash points are reached. When fixed oils are heated sufficiently to give off vapors, destructive distillation has already begun, and it will be seen from the table (page 23) that the flash points of fixed oils are much higher than for mineral oils of similar viscosities, the open flash points ranging from 460 to 630°F.

The difference between the open flash point and the fire point of lubricating oils is approximately as follows:

	Difference between Open Flash Point and Fire Point, Degrees Fahrenheit
1. Straight mineral distilled lubricating oils	40 to 55
2. Cylinder oils (undistilled)................	50 to 75
3. Mixtures of mineral distilled oils with cylinder oils or fixed oils................	40 to 75

The *evaporation point* is the temperature at which an oil begins to give off vapors; this temperature is normally about 150 to 180°F. lower than the flash point but is so difficult to determine accurately and depends so much on the human element that its determination is of no practical importance.

Volatility—Loss by Evaporation.—Oil exposed to a high temperature for a certain number of hours loses a certain amount in weight, which is called "loss by evaporation."

The oil is usually heated in an open beaker, and experience shows that the loss by evaporation is greatly influenced by the size and shape of the beaker, the amount of oil used, air currents, etc. When giving figures for loss by evaporation, one should

therefore state all such particulars, for the test to be of any value at all.[1]

The evaporation test is seldom of any great value; if a lubricating oil has an open flash point above 300°F., the loss by evaporation will usually be of no importance; the flash point will prove a safe guide as to whether the oil contains light petroleum fractions of a kerosene or gasoline nature.

Where oils are known to be contaminated with low-flash products, the evaporation test can be used to determine the percentage present of these products, *e.g.*, with used oils from the crankcase of gasoline or oil engines.

Lubricating oils used for high-vacuum pumps (in the manufacture of electric bulbs) must have a low volatility in vacuum and should have their vapor tension tested, when exposed to vacuum and at a temperature approximating the working temperature.

Transformer oils are often subjected to the evaporation test, as many of these oils are low-flash oils (occasionally flashing below 300°F.), and the loss by evaporation during use may easily become an important feature.

Air-compressor oils are sometimes tested with advantage for evaporation losses, particularly when the compressed air is used for tunnel work or for operating tools or engines in confined spaces or in underground mines, as the presence of an appreciable amount of oil vapor in the compressed air will affect the eyes and throats of the workers.

Archbutt has designed a simple vaporimeter,[2] in which the oil is placed in a boat inside a 7/8-in. internal-diameter tube, through which is passed hot air or steam, the whole heated to the desired temperature by means of a gas burner. The apparatus appears to give very consistent results and to lend itself well to standardization.

The vessels used for evaporation tests should be porcelain or glass; metal vessels have a catalytic effect, which influences the results.

From tests carried out by Archbutt and others, it is evident that no simple relation (if any relation at all) exists between the volatility of an oil and its flash point.

[1] The evaporation per square centimeter of surface is a better guide than the loss per gram of oil.

[2] ARCHBUTT and DEELEY, "Lubrication and Lubricants," p. 215.

Distillation.—In rare cases lubricating oils are subjected to distillation tests with a view to finding out the percentages of low-viscosity, medium-viscosity, and high-viscosity oils of which they are composed.

All lubricating oils are mixtures of hydrocarbons having different viscosities; and while it is not of any considerable interest further to analyze from a distillation point of view the main types of oils referred to on page 10, yet it may be of interest to find out whether a certain lubricating oil is a mixture of cylinder stock and a lower viscosity distilled lubricating oil and, in that case, what the percentage of cylinder stock amounts to.

No standard method has been adopted for a distillation test of lubricating oils, nor does this test seem to be of particular interest to ordinary consumers. On the other hand, it may be of considerable interest to oil refineries or lubricating-oil companies with a view to finding out the characteristics and component parts of competitive products.

Dilution Test.—This test is now one of the A.S.T.M. standards by which is determined the amount of gasoline that has diluted the crankcase oil in automobile engines (see page 507).

Specific Heat.—The specific heat of a lubricating oil means the amount of heat required to raise the temperature of 1 lb. of oil 1°F. or 1 kilo of oil 1°C., as compared with the amount of heat required to heat 1 lb. of water 1°F. or 1 kilo of water 1°C., respectively. The specific heat of water is therefore 1.00.

A considerable amount of work in connection with specific heats of oils has been done by Prof. Charles F. Mabery.[1]

Professor Mabery has shown that the specific heats of the paraffin series of hydrocarbons are higher than the specific heats of the naphthenes, olefins, and other hydrocarbons less rich in hydrogen than the paraffins.

The specific heat is higher for the lower viscosity oils than for those of higher viscosity, although the difference amounts to only a few per cent. The specific heat also increases slightly with increasing temperatures.

For practical purposes, however, the specific heat may be taken as follows:

[1] *Proceedings* American Academy of Arts & Sciences, vol. 37, p. 20, March, 1902.

Mineral lubricating oils	Character of hydrocarbons	Specific heat at 50°C.
Paraffin-base distilled low-viscosity oils...........	C_nH_{2n+2}	0.49
Russian oils and heavy-viscosity Pennsylvanian oils, etc....................................	C_nH_{2n}	0.47
Many asphaltic-base oils........................	C_nH_{2n-2}	0.44

The preceding values for specific heat show a characteristic difference between the different lubricating oils, which is of some importance in connection with lubrication, as the frictional heat developed during the operation of machinery heats the oil film, thus reducing its viscosity. The lower the specific heat the greater will be the temperature rise of the oil in the film, and therefore the greater will be the reduction of viscosity.

Setting Point or Cold Test, Pour Test, and Cloud Test.—When lubricating oils are cooled they do not congeal suddenly, as, for example, water congeals when it turns into ice, but, being mixtures of products of different nature, they gradually become more and more viscous until they finally set solid; the temperature at which they congeal is called the "setting point," or "cold test."

The lowest temperature at which the oil will flow or pour out of a receptacle is usually taken as being 5°F. above the setting point and is called the "pour test."

The temperature at which the oil starts to become cloudy—paraffin wax separating out—is called the "cloud test," but it is difficult to determine this temperature with accuracy, and the cloud test is nowadays rarely spoken of in connection with lubricating oils.

Stirring.—When the setting point of mineral oils is being determined, the oil must not be stirred, as by stirring the network of solid hydrocarbons is broken up, and the setting point will be from 5 to 10°F. lower than when the oil is cooled without stirring. Archbutt, however, recommends stirring when testing fixed oils.

Russian oils, Californian, and other nonparaffinic-base oils have no cloud test, as they contain no solid paraffin; their setting points are therefore lower—from 20 to 40°F. lower than those of paraffin-base oils.

Sometimes heavy-viscosity paraffin-base oils become chilled during transit in cold weather; as a result, the amorphous wax begins to solidify in oily lumps throughout the body of the oil. The oil will therefore be much thicker than its standard (real) viscosity and will not be homogeneous. To bring the oil back to its normal viscosity, it is necessary to heat it sufficiently to melt the paraffin wax, say, to 160 or 170°F., the melting points of paraffin wax ranging from 100 to 130°F.

When light-viscosity lubricating oils become chilled, some of the paraffin wax sometimes crystallizes out in the form of shiny needles floating in the oil; they will dissolve in the oil only if heated to a temperature above their melting point.

Heating.—When testing the setting point of oils containing paraffin wax, they should, for the reasons just given, always be previously heated to a temperature of 160 to 170°F.

Cooling.—The oil should be cooled slowly, as rapid cooling means that the setting point, as determined, will be too low. This is particularly important for fixed oils. The test tube or bottle containing the oil should therefore be placed inside another tube ½ in. larger in diameter, the air space between the tubes preventing too rapid cooling.

Apparatus.—There is a variety of apparatus employed for testing the setting point, pour test, and cloud test of oils. Some aim at determining the setting point as the temperature at which the oil in the vicinity of the thermometer ceases to flow when the vessel or tube is tilted for 10 min. Others aim at determining the pour test as the temperature at which a definite quantity of the oil will just flow from end to end of a test tube of definite dimensions when placed horizontally or inverted; this method is used largely for cylinder oils and black oils.

The determinations of setting point or pour test are usually accurate within 5°F.

Cooling Mixtures.—For oils congealing above 35°F., pounded ice is used. For oils congealing at from 35 to −5°F., a mixture of snow or pounded ice and salt is used, the salt preferably being added gradually to bring the temperature down 5°F. at a time.

For oils congealing below zero, solid carbon dioxide can be used or calcium chloride (crystals) and ice (−40°F.), or solid carbon dioxide may be added to dry acetone, by which a temperature as low as −70°F. can be obtained.

The setting point of an oil must be low enough so that the oil will flow readily under working conditions and so that a sufficient amount will reach the bearings or parts to be lubricated. Many mishaps have been caused by the oils solidifying in the lubricators or refusing to run through exposed oil pipes to the bearings. While, therefore, in tropical or warm climates the setting point of lubricating oils ordinarily is of no importance, this feature is certainly important in temperate climates and particularly in colder climates like those of Canada, northern Scandinavia, and northern Russia.

Oils used for refrigerating machines and other special machines must always have low setting points, independent of the climatic conditions. Low setting point must be given special consideration in connection with engines or machinery operating in the open, such as railway rolling stock, certain machinery in mines and quarries, airplanes, automobiles, etc. Oils used for engines or machinery operating inside buildings do not require the same consideration as regards setting point.

Whenever low-setting-point oils are required, the winter conditions are, of course, more severe than summer conditions; and so, frequently, two sets of oils are used—for summer and for winter use, respectively.

Melting Point.—The melting point of an oil, fluid at ordinary temperatures, is the same as its setting point, or rather its pour test; in fact, the latter is sometimes determined by freezing the oil solid, then allowing it to melt exposed to the room temperature, under continuous stirring, until the oil starts to pour. The melting point of fats, lubricating greases, or oils nonfluid at ordinary temperatures is not a definite temperature, as they become soft and gradually melt, when heated.

Melting points of fats and greases may be determined in several ways, as described by Archbutt;[1] no uniform system has been agreed upon, and there are great discrepancies between the results when different apparatus is used and by different observers.[2]

[1] *Op. cit.*, pp. 223–229.

[2] Very low-melting-point greases (m.p. 20 to 30°C.) are required for gearboxes of automobiles, pneumatic tools, etc. Such greases may simply be poor cold-test cylinder stock.

Low-melting-point greases (m.p. 40 to 50°C.) are required for railway axle-box lubrication. Medium-melting-point greases, such as cup greases or solidified oils (m.p. 75 to 95°C.) are used for general lubrication. High-melting-point greases are used for high-temperature bearings for rotary cement kilns, dryer journals and calendar journals on paper machines, beater bearings, etc. (m.p. 150 to 250°C.).

Color and Fluorescence.—Fixed oils are transparent and either almost colorless or slightly yellow or greenish yellow in transmitted light.

Distilled mineral oils are transparent and range in color from water-white, through yellow, to deepest red in transmitted light.

Undistilled mineral oils—cylinder stocks—are very dark in color; dark cylinder stocks range from dark brownish red to black, whereas the filtered cylinder stocks are lighter in color and range from deep red to deepest red in transmitted light.

Lovibond's tintometer may be used to determine by comparison with standard colors the color of oil in, say, a 1-in. cell. The darker the oil the higher is the color number. If determined in a cell of different thickness, the thickness of the cell should be stated, so that the color number may be calculated in terms of a 1-in. cell.

An apparatus has been designed employing a photocell. The oil is placed in a glass container, and the photocell measures the amount of light absorbed in passing through the oil. By interposing glasses of different colors between the source of light and the cell, the absorption of the various colors can be measured, thus giving a complete picture of the true color of the oil expressed in shades of yellow, blue, and red.

Wearham has designed an apparatus that gives the color of an oil or any other material, liquid or solid, in terms of percentages of primary red, blue, and yellow. The color determined in this manner is definitely expressed and can be reproduced in the apparatus to act as a standard for matching colors at the refineries or oil-blending works.

The color of an oil in reflected light is called "bloom" or fluorescence.

Paraffin-base oils have a greenish bloom; Russian and many asphaltic-base oils have a bluish bloom. Dark cylinder stocks

are dark brown or black, whereas highly filtered cylinder stocks show the fluorescence clearly and are usually green, being produced from paraffin-base crudes.

Oils that during use have been oxidized (turbine oils, crankcase oils, etc.) almost immediately change their bloom and assume a brownish color in reflected light. Oils that contain moisture become cloudy or even opaque and appear to be darker in color than when dry.

Coloring matter in oil consists of very complex unsaturated hydrocarbons, which easily decompose under heat or when exposed to oxidation. Dark-red oils when used for internal-combustion engines or air compressors therefore produce more carbon than pale oils, and dark-colored circulation oils are more inclined to produce deposits in steam turbines and enclosed-type steam engines than are pale oils. Similarly, dark cylinder oils produce more carbon than filtered cylinder oils when used for steam engines employing superheated steam.

Where oils are not exposed to great heat or oxidation, it is immaterial whether they are lighter or darker in color.

Viscosity of Oils.—The viscosity of an oil is a measure of its resistance to flow—its internal friction—and is inversely proportional to its fluidity. A viscous or high-viscosity oil is "thick" and flows with difficulty; a low-viscosity oil is "thin" and flows readily.

The most accurate method of determining viscosity which is used chiefly in science is that of Poiseuille, by measuring the rate of flow of the oil through a capillary tube (a very narrow tube) under known conditions of temperature and pressure.

For commercial purposes the viscosity is usually determined by measuring the time taken in seconds for a certain volume of oil to flow out through a short vertical tube of standard dimensions.

Poiseuille's Method.—Poiseuille's method is based upon two facts, which he proved experimentally:

1. That the rate of flow of liquid through a capillary tube of suitable dimensions is proportional to the pressure and inversely proportional to the length of the tube.

2. That the rate of flow through a capillary tube of cylindrical bore is proportional to the fourth power of the radius of the bore.

The viscosity of the fluid in absolute measure is then given approximately by:

$$\textit{Absolute viscosity} = \eta = \frac{\pi g d h r^4 t}{8Va}$$

where g = acceleration due to gravity.
d = density of the liquid.
h = mean head.
r = radius of the bore of the capillary tube in centimeters.
t = time in seconds.
v = volume of liquid discharged in cubic centimeters.
a = length of the tube in centimeters.

Reynolds has shown that Poiseuille's formula is substantially correct when $\frac{rvd}{\eta}$ is less than 700 where v is the mean velocity of the fluid.

To obtain the true viscosity, corrections must be made

1. For the viscous resistance to the flow of the liquid at the ends of the tube.
2. For the abnormal flow of the liquid on first entering the tube.
3. For the kinetic energy with which the liquid leaves the tube.
4. For the resistance due to surface-tension effects at the discharge orifice.

Corrections 1 and 2 have not yet been devised, but errors due to these effects may be reduced to very small proportions by making the tube long. Correction 3 is made by deducting from the mean head a quantity v^2/g; this correction may be made very small by using a tube so narrow and so long that the movement of the liquid is very slow. The error due to surface-tension effects, which may be serious, is so variable that correction 4 is best eliminated altogether by immersing the discharge orifice in the liquid and making a suitable deduction from the head.

The absolute viscosity of a liquid may be defined as the force that will move a unit area of plane surface with unit speed relative to another plane surface from which it is separated by a layer of the liquid of unit thickness.

The absolute viscosity is therefore correctly expressed in dyne seconds per square centimeter but is usually referred to as dynes per square centimeter.

The term "poise" has been coined from the name of Poiseuille and signifies 1 dyne sec. per square centimeter. As an absolute viscosity of 1 poise means a fairly viscous oil, the term "centi-

poise" is used, representing 0.01 poise, just as 1 cm. equals 0.01 m.

The kinematic viscosity in the c.g.s. system is obtained by dividing the absolute viscosity with the specific gravity of the oil. These kinematic viscosities are called "stoke" and "centistoke," corresponding to poise and centipoise.

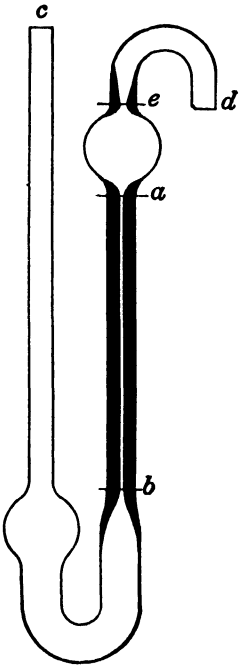


FIG. 1a.—Ostwald's viscometer.

Ostwald's viscometer (Fig. 1a) is capable of giving the true relative viscosity in terms of the viscosity of water or other standard liquid, which is called the *specific viscosity*, when compared with the viscosity of water at 20°C. as unit. It consists of a glass U tube, one limb of which is a capillary tube from a to b. A known volume of oil is introduced into the wide limb at c and sucked up at d, until the level is above e. The time occupied in flowing back through the capillary ab while the level falls from e to a is noted.

If td and t_1d_1 are the time of flow and density of the liquid and water, respectively, and if the viscosity of water is taken as unity, then the

$$\text{Specific viscosity} = \frac{td}{t_1d_1}$$

As the tendency is more and more to indicate viscosities in absolute units, there is a growing need to have a commercial apparatus for this purpose. Recently, such apparatus have been proposed, one being a modified Ostwald viscometer and the other the Ubbelohde suspended-level method, both of which have been published by Committee D-2 of the A.S.T.M.

Commercial Viscometers.—The most widely used instruments are Saybolt (United States), Redwood (Great Britain), and Engler (Continent).

These instruments are described in greater detail in most standard handbooks.

The viscosities for Saybolt and Redwood are given in seconds, whereas with the Engler instrument, the Engler number equals the outflow in seconds divided by the efflux time of water at 20°C., which is 50 to 52 sec., varying slightly for different instruments.

The Engler number is therefore a kind of specific viscosity and can be converted into absolute viscosity by the chart on page 54.

All three viscometers have efflux tubes so large and comparatively short that a large proportion of the energy of flow, particularly for low-viscosity liquids, is carried away in the issuing stream of liquid and not used for overcoming the fluid friction inside the efflux tube. For example, with the Engler viscometer the percentage of energy used in overcoming fluid resistance within the efflux tube is 95 per cent or more in the case of a heavy-viscosity oil, whereas with water it is only about 12 per cent.

The relation between the absolute viscosity of an oil and its kinematic viscosity, as measured by Saybolt, Redwood, or Engler viscometers, is fairly uniform for medium- or heavy-viscosity oils, but when the kinematic viscosity is lower than, say, 100 sec. Saybolt, the absolute viscosity falls away more rapidly than the corresponding kinematic viscosity figures.

Viscometers should be calibrated by testing the viscosity of a standard liquid, as water, mixtures of glycerin and water, cane-sugar solutions, etc. Rape oil or sperm oil as recommended by some for standardizing viscometers varies too much in viscosity to be used for standardizing purposes.

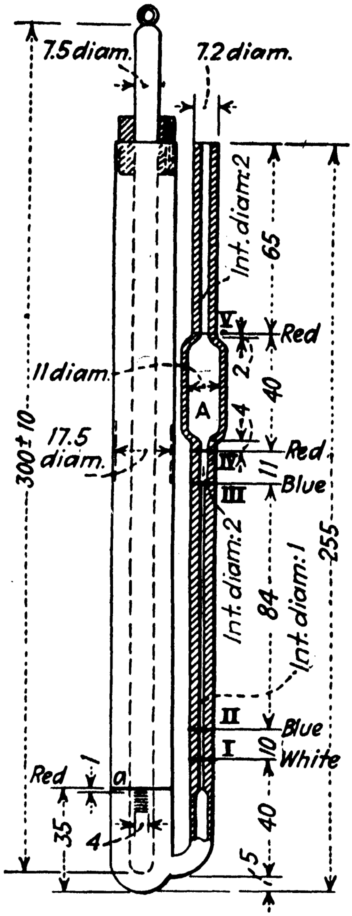


Fig. 1b.

A commercial apparatus for determining the kinematic viscosity in the c.g.s. system is proposed by Raaschou (Laboratory of General Technical Chemistry of the Technical University of Denmark). This viscometer permits viscosity determinations over a wide range. It is designed with a view to reducing to a minimum deviations originating from the difference in the capillary action of liquids.

The viscometer whose dimensions are given in Fig. 1b is U-shaped. One side is a wide glass tube. The other side, the

capillary side, is by the bulb portion A with a capacity of about 2.5 ml. divided into an upper and a lower capillary tube.

The wide tube has an annular red mark a at the bottom and millimeter division downward as shown. A thermometer is placed axially in the tube sliding in a cork stopper with lateral slit. The thermometer serves partly to control the temperature of the sample, wherefore it should be calibrated (standard thermometer), and partly to adjust the heights of liquid before the measurement commences.

On the capillary-tube side, the lower capillary tube has a white mark I, and two blue marks II and III. Just below and above the bulb A, two red marks IV and V are placed.

It is practical to place the viscometer in a metal stand, when in use, whereby it is protected against breakage, and the capillary-tube side is connected to a suction device, *e.g.*, a syringe. For the connection a rubber hose with inside diameter 4 mm. and outside diameter 7 mm. may conveniently be used. Near the suction device a three-way cock is inserted to make a connection between the viscometer and the atmosphere and also between the viscometer and the suction device. The rubber hose is given such a length that the three-way cock and the suction device may rest on the work table.

When the viscosity determination is to be made, the stand with the viscometer is placed in a thermostat in which the temperature can be adjusted with an accuracy of at least 0.1°C.

Procedure.—The viscometer may be employed in two ways, A and B, according to whether the oil sample is thin (ν from about 1.5 to about 100 cS), or viscous (ν from about 100 to 5,000 cS).

A. The viscosity of liquids of comparatively low viscosity is determined by introducing the sample into the clean viscometer until the liquid surface in the wide tube is from 3 to 5 mm. below the mark a. Then the stopper with the thermometer is placed in the wide tube, and the viscometer is immersed vertically into a liquid bath of the temperature at which the viscosity is to be determined so that the mark V on the capillary tube side is a little below the surface of the bath.

When the sample has assumed the temperature of the bath, *the liquid surface at the wall in the wide tube is adjusted to the mark a by pushing the thermometer.* Then the sample is sucked up

into the capillary-tube side until the liquid surface is a couple of millimeters above the mark V, when the three-way cock is opened to the atmosphere and the efflux time of the liquid *from the mark V to the mark IV* (the red marks) is determined by means of a stop watch.

A mean figure t is taken for the efflux time in seconds of at least two determinations which do not differ by more than 0.5 per cent from each other.

B. The viscosity of liquids *with relatively high viscosity* is determined by introducing the sample into the viscometer as described above, and causing it to assume the test temperature. *Then the liquid surface is adjusted by pushing the thermometer so that the miniscus, when the liquid column falls, will settle at the mark I on the capillary-tube side.* The liquid is then sucked up into the lower capillary tube until the surface is a couple of millimeters above the mark III, the three-way cock is opened to the atmosphere, and the efflux time *from the mark III to the mark II* (the blue marks) is determined by means of a stop watch.

A mean figure t is taken for the efflux time in seconds of at least three determinations which do not differ by more than 1 per cent from each other.

The kinematic viscosity determined in this manner is then:

$$\nu = k_A \cdot t \text{ (method A)}$$

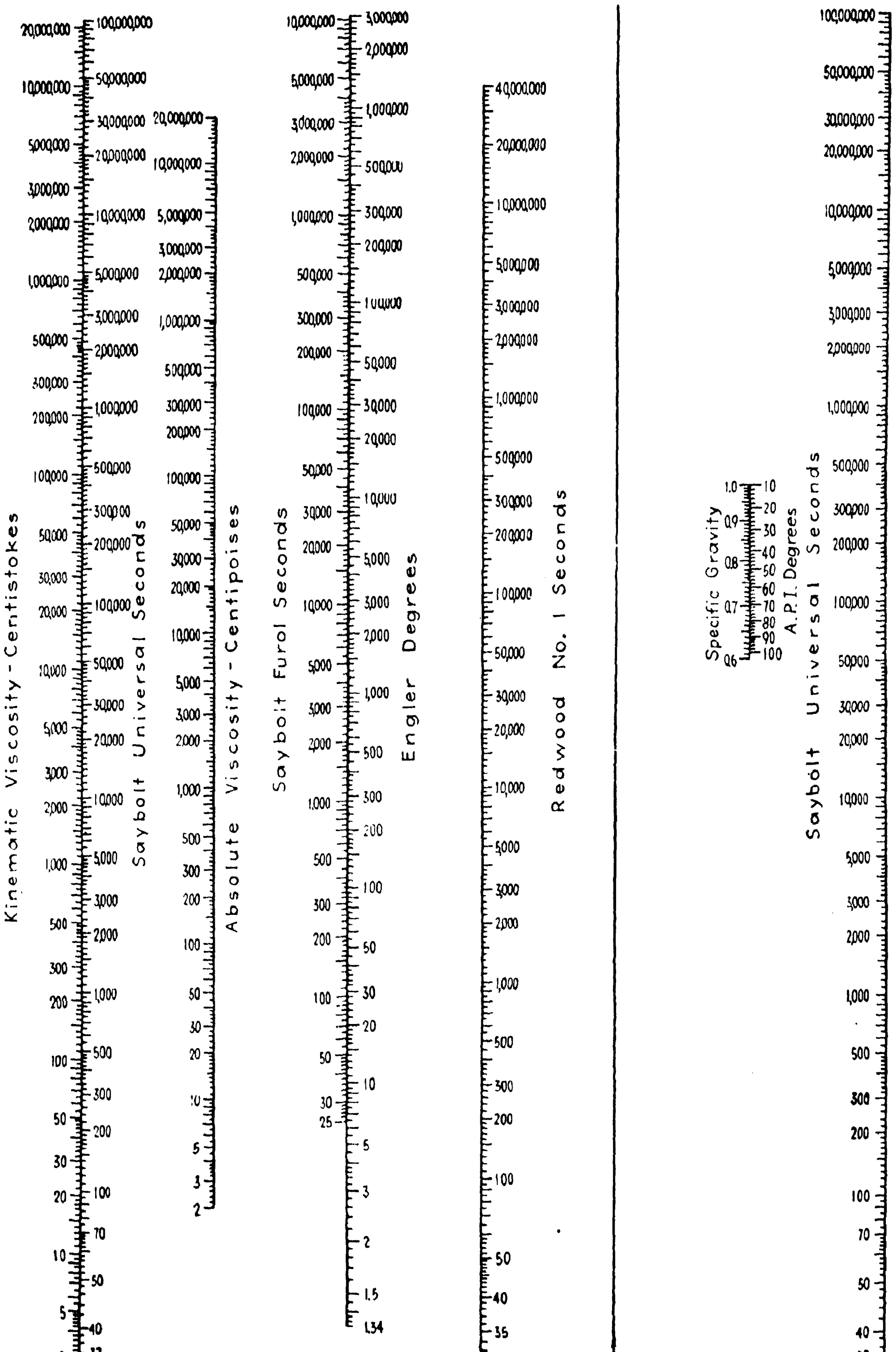
or

$$\nu = k_B \cdot t \text{ (method B)}$$

where k_A and k_B are calibration constants which have been determined according to the above method with a liquid of known kinematic viscosity, *viz.*, a mineral oil having a ν of about 150 cS at 20°C., and whose viscosity is accurately determined by The National Physical Laboratory, Teddington, England.

When particulars of the viscosity of an oil are given, important details are often omitted. Sometimes the name of the viscometer is not given or the temperature at which the viscosity is taken. Furthermore, if it is desired to calculate the absolute or the specific viscosity, it is necessary also to know the specific gravity.

The *National Petroleum News* has published an excellent chart (see page 54) by means of which kinematic viscosities may be



Viscosity conversion chart. (*National Petroleum News.*)

readily converted from the values obtained by one instrument to those obtained by another (Saybolt, Redwood, Engler, and kinematic c.g.s.) simply by drawing a horizontal line.

Connecting the point marking the kinematic viscosity in centistokes on the vertical line to the left with the point marking the specific gravity on the vertical line to the right, this line crosses the vertical line for absolute viscosity (second from the left) at a point giving the absolute viscosity in centipoises.

Temperatures.—Viscosity figures quoted at 70°F. are going out of use, and rightly so, as the oil is very rarely at this temperature during actual use. For oils used externally, the important viscosities are those taken at 104°F. (40°C.) and 140°F. (60°C.), as the temperature of the oil film will range somewhere between 30 and 50°C. for ordinary bearings and between 50 and 70°C. for bearings in steam turbines, enclosed high-speed steam engines, and many internal-combustion engines.

For steam-cylinder oils the viscosity is usually taken at 212°F. To test the viscosity at higher temperatures, in addition to the 212°F. figure, does not appear to be of any value; although viscosity is important, there are other and more important properties than viscosity which determine the lubricating quality of cylinder oils.

For oils like air-compressor oils and internal-combustion engine oils, where fairly low-viscosity oils are used, the viscosity should be measured at 104 and 212°F.

When the setting point of an oil is known and at least two viscosities, preferably three, a viscosity curve can easily be drawn from which can be measured the approximate viscosity figures at intermediate temperatures. Commercial measurements of viscosity are usually accurate within 1 per cent.

Oils change in viscosity with change in temperature (ranging normally from 0.6 to 6.0 per cent per degree Fahrenheit between 104 and 212°F.). The change per degree Fahrenheit is greater for mineral oils than for fixed oils, greater for high-viscosity than for low-viscosity oils, greater (at high temperatures) for asphaltic- and naphthenic-base than for paraffin-base oils. The increase per degree Fahrenheit becomes very great when approaching the setting-point temperature of the oil. As nonparaffinic-base oils have low setting points, their increase in viscosity at low temperatures is usually less than for paraffin-base oils. Hence, for

cold conditions or climates the former oils have better viscosity curves at the working temperatures.

The following figures show the difference in character between paraffin-base and nonparaffinic-base oils.

	Californian oil	Russian oil	Paraffin-base oil	Texas oil	Paraffin base
Saybolt viscosity					
At 212°F.	48	51	49	73	74
At 140°F.	147	150	110	360	250
At 104°F.	430	400	269	1,200	700
Cold test	0°F.	0°F.	25°F.	20	40
Average change in viscosity per degree Fahrenheit:					
From 212 to 140°F.	2.9%	2.7%	1.7%	5.4%	3.3%
From 140 to 104°F.	5.4%	4.6%	4.0%	6.5%	5.0%

At temperatures below 104°F. the viscosity curves are very steep, and the increase in viscosity per degree Fahrenheit is still higher, particularly so for oils having poor cold tests, as is the case with paraffin-base oils, or mixtures containing poor cold-test cylinder stock or a large amount of fixed oil or fat. When the viscosity curve is very steep around 70°F., it means that if the oil is supplied through gravity feed oilers, siphon oilers, and the like, even slight changes in temperature will appreciably affect the oil feed—an undesirable feature.

At high temperature the fixed oils maintain their viscosities remarkably well, which is one of the minor reasons why fixed oils are better lubricants for bearings inclined to heat because of bad mechanical conditions, excessive bearing pressures, etc.

Variations in viscosity due to temperature changes are in Europe often expressed by formulas that give the steepness of the viscosity curve on the basis of absolute viscosities; it is unfortunately cumbersome to apply these formulas. In the United States the so-called "viscosity index" is often employed, expressing the variation in viscosity in relation to two oils chosen at random (Pennsylvania oil, 100; asphaltic oil, 0). The disadvantage is that owing to modern improved methods of oil refining, we now

TABLE OF VISCOSITIES*

Viscosity numbers	Saybolt seconds			Redwood seconds			Engler number			Absolute viscosity centipoises			
	100°F.	130°F.	212°F.	70°F.	140°F.	200°F.	20°C.	50°C.	100°C.	40°C.	50°C.	60°C.	100°C.
1	65	45	29	75	32	.....	2.7	1.4	....	9	4.5	2.7	
2	80	50	31	120	40	.....	4.4	2.0	....	12	8	5.3	
3	95	60	32	135	46	.....	4.8	2.2	....	15	10	7.5	
4	125	70	34	250	55	.....	9.0	2.6	....	20	13	9.2	
5	160	81	36	300	60	.....	12	3.0	....	25	18	12.0	
6	180	86	38	335	65	.....	13	3.3	....	30	20	12.5	
7	240	115	43	500	85	.....	18	4.0	....	40	26	17	
8	350	160	50	800	115	.....	27	6.0	...	60	38	25	
9	500	230	55	1,200	160	...	45	8.0	...	90	56	36	
10	700	320	65	2,000	210	...	65	10.5	2.0	120	76	48	10
11	.....	...	80	.....	...	80	...	....	2.5	...	...	....	14
12	1,400	470	90	5,000	300	90	175	18.0	2.8	235	125	72	16
13	1,800	600	100	9,000	380	100	300	22.0	3.0	300	165	90	18
14	.....	...	130	.....	...	130	.	..	3.3	...	...	....	26
15	.....	...	165	.....	...	165	...	...	4.0	...	...	.....	32
16	.....	...	190	.....	...	190	...	....	6.0	..	...	....	40
17	Blown oils		700	.....	...	700	.	....	8.0	...	...	....	150
18			1,400	.....	...	1,400	..	....	10.5	...	...	....	300

* The viscosity figures given in the foregoing table are only approximately correct, but they will serve as a guide to convert viscosities from one "viscosity language" into another. Furthermore, this table will help the reader to determine the nearest grade of oil corresponding to those oils which the author recommends throughout this book, the viscosities of which will be referred to only as one of the numbers from 1 to 18, indicated above.

produce oils that may get placed outside the interval 0 to 100; we get oils with a viscosity index above 100 and also oils with a negative viscosity index. The ideal would be to find formulas that in a simple, practical manner would express the viscosity of an oil in absolute units at different temperatures, based upon the viscosity of that oil at two temperatures, its specific gravity, and/or its molecular weight.

The viscosity of oils when measured under great pressure[1] is much greater than the ordinary viscosities, which are measured under atmospheric pressure. Mineral oils vary considerably among themselves and generally have a high rate of increase in viscosity with pressure. The fixed oils, however, do not greatly differ from each other and show an increase in viscosity at 1,000 atmospheres to approximately four times their values at atmos-

[1] Experiments by Dr. T. E. Stanton and Mr. J. H. Hyde, National Physical Laboratory, Teddington.

pheric pressure, compared with anything between ten and twenty-five times the corresponding values for the mineral oils.

When oils are standardized for viscosity, it is customary to allow a manufacturer's variation of 4 to 6 per cent above and 2 to 3 per cent below the standard; the permissible variation above the standard is the greater of the two, because too high a viscosity is usually less objectionable under the conditions of service than too low a viscosity.

Comparing two oils having the same kinematic viscosity, say the same Saybolt viscosity, the heavier oil of the two (the one having the highest specific gravity) really is the more viscous, because, being heavier, it flows out of the viscometer more rapidly than it would if it were lighter in specific gravity. The real viscosities of nonparaffin-base oils are therefore about 5 per cent higher than their kinematic viscosities lead one to expect when comparing them with paraffin-base oils. Much confusion has been caused by expressing the viscosities of oils in terms of kinematic viscosities, and it would be very desirable if users of oil would insist upon viscosities' being measured or specified as *absolute viscosities*, which represent their *true viscosities* and consequently form a much better basis for comparing the suitability of different oils.

The viscosity is frequently the most important property of a lubricating oil. With perfectly lubricated frictional surfaces (complete oil film), the friction is directly proportional to the viscosity of the oil, and mineral oils are always used. With less perfectly lubricated surfaces the oiliness of the oil becomes important, and compounded oils are frequently used. Under very severe conditions of pressure (incomplete oil film) the viscosity value of the lubricant is no guide at all; the oiliness becomes the all-governing factor, and fixed oils or oils rich in fixed oils have to be used.

Speaking generally, high-viscosity oils are required for conditions of high temperature or great pressure or slow speed. Low-viscosity oils are required for conditions of low pressure or high speed. For low-temperature conditions it is low setting point that governs the selection of oil more than viscosity.

When blending oils of different viscosities in certain proportions, it is important for oil manufacturers to be able to find out the viscosity of the blended oil. The A.S.T.M. has made an

excellent chart from which, by merely drawing one line upon it, the viscosity of the blended oil can be obtained with great accuracy.

Viscosity of Semisolid Lubricants.—Cup greases, solidified oils, etc., are generally sold in five standard consistencies—very soft, soft, medium, hard, and very hard.

The consistency varies with the temperature of the grease, and the consistency of a sample of grease is a matter of personal judgment developed by experience. Several attempts have been made to devise an instrument for measuring the consistency—viscosity—of a grease, but none has been of any practical value. Several instruments have a weighted needle, which is allowed to penetrate for a certain number of seconds or until it stops because of skin friction; the observations are very irregular even with the same sample of grease, owing to local variations in consistency. In other instruments the grease is squeezed through a small opening by a definite force; here, again, results are most erratic and misleading.

One reason—probably the chief reason—for these failures is that all greases have a peculiar "set," or "honeycomb" nature; once the grease has been handled, the honeycomb structure is broken up, and the grease becomes softer and more oily in appearance. To show this effect, the author forced a certain amount of a medium cup grease through a 3/8-in. nozzle by the force of a 28-lb. weight. The grease came through the first time in 126 sec. On putting the same grease back in the test cup and repeating the performance, the efflux times for the succeeding three tests were 47, 13, and 6 sec., respectively.

Many engineers will have noticed that when working grease by the fingers and hands it becomes softer and softer. The author also tried various petroleum-jelly greases by a grease viscometer and found the results fairly consistent, presumably because these greases do not possess that peculiar structure characteristic of cup and other soap-containing greases.

Capillarity.—All lubricating oils have the property of rising into siphons or wicks made of wool or cotton, but the capillary power differs considerably for different oils.

Railway and steamship companies, many of which employ to a large extent siphon lubrication or pad lubrication, find it very useful to compare lubricating oils for capillary power, as it is

upon this property that their siphoning ability largely depends. Obviously, the best method is to test the oils in an actual box of the exact type used on the railway or steamer and to test the oils over the whole range of temperatures to which they may be exposed during service.

The quality of the wool is important. Berlin wool, which is of a soft, loose texture, has greater siphoning ability than closely twisted worsted yarn.

The siphoning ability of lubricating oil is influenced largely by the viscosity of the oil and by its nature, whether pure mineral or containing a percentage of fixed oil. The lower the viscosity the quicker will the oil siphon from the lubricator cup into the bearing.

Emulsification.—Circulation oils which are used in connection with steam turbines, enclosed-type steam engines, etc., come into contact with water and must not form an emulsion with it. Animal and vegetable oils emulsify quickly when churned together with water, so that it is out of the question to use these oils in circulation systems where there is danger of water's being present. Mineral lubricating oils have a low affinity for water, but experience has proved that this affinity is sufficiently strong in most of them to cause frequent trouble. The tendency to emulsify differs considerably for different oils, and it therefore becomes necessary to subject circulation oils to an emulsification test.

This test may be carried out by shaking definite quantities of oil and water either by a reciprocating motion in a bottle or by churning the oil and water together by a paddle wheel revolving at high speed. The water may be distilled water, salt water, or a caustic-soda solution, according to the requirements that the oil has to meet. Marine-turbine oil, for example, must separate from salt water in such cases where a leakage of salt water into the system cannot easily be prevented.

Where boilers prime, and boiler impurities are likely to be carried over into steam turbines or enclosed-type steam engines, it may be of interest to use a caustic-soda solution or even the boiler water itself when making the emulsification test.

The test should be carried out at about 130°F., which is the average temperature of circulation oils when in service, and the mixture should be allowed to settle at a similar temperature.

Ferric oxide or iron salts have a most powerful emulsifying effect on circulation oils in the presence of water. If only a fraction of 1 per cent iron salts is added to the water used for the emulsification test nearly all oils will show a very considerable percentage of sludge. It will appear that it is the presence of a quite small percentage of certain unstable hydrocarbons, sulphur compounds, naphthene salts, etc., that causes emulsification.

Filtered oils that have not been acid treated show less tendency to emulsification than acid-treated oils and should therefore be used in preference to the latter in the manufacture of circulation oils. When manufacturing heavy-viscosity circulation oils, it is often necessary to use an admixture of filtered cylinder oil or bright stock, which has not been treated with acid but merely filtered to remove unstable hydrocarbons, etc., and are therefore eminently suitable for the purpose. Well-filtered cylinder stocks have only a slight tendency to emulsification.

Speaking generally, low-viscosity, low-specific-gravity oils give better service as circulation oils than heavy-viscosity, heavy-specific-gravity oils, because they separate more quickly from water, dirt, and other impurities.

Attempts have been made to express the tendency of an oil to emulsify in terms of its "emulsification value," an emulsification value of 98 per cent meaning that 98 per cent of oil separated out in the emulsification test, 2 per cent being retained in the sludge.

Even if an oil shows great resistance to emulsification, it is desirable to know how rapidly the separation takes place. When in an emulsification test the mixture of oil and water is allowed to separate, some oils will separate out in a few minutes, whereas others may take half an hour or more, and yet the final separation may not show any formation of sludge. Obviously, quick separation is exceedingly important, as in most circulation oiling systems the oil is not given much time to free itself from water.

An apparatus to determine the demulsibility, *i.e.*, resistance to emulsification, of an oil and to express this quality by a figure has been devised by W. H. Herschel (described in U. S. Bureau of Standards, Bulletin 86). In this apparatus oil and water are churned by a paddle for 5 min., and a record taken of the time in minutes taken for separation.

The demulsibility figure D is calculated as the rate of oil settling out per hour and is therefore expressed as

$$D = 60 \times \frac{v}{t}$$

where v = the volume of oil in cubic centimeters that has separated out.
t = the time in minutes taken for the oil to separate out.

The maximum demulsibility figure is 1,200; *i.e.*, the entire volume of oil (20 cc.) separates out in 60 sec. If with a poor oil only 10 cc. separate out in, say, 15 min., the demulsibility value is

$$60 \times \frac{10}{15} = 40$$

Surface Tension.—There can be no doubt that the surface tension of an oil has some influence on the condition and strength of thin oil films in contact with metallic surfaces. Lubricating oils wet metallic surfaces, as their surface tensions are lower than those of metals. Differences in surface tension as between various lubricants will therefore mean different behavior as to their tendency to wet metallic surfaces, but the exact nature and importance of surface tension in connection with lubrication is still a practically unexplored subject.

CHEMICAL TESTS

Acidity.—Free acid in lubricating oils may be present as free mineral acid, petroleum acid, fatty acid, or rosin acid.

a. Free sulphuric acid or other mineral acid which has been used in the refining of the oil. It is very rare nowadays to find any objectionable percentage of free acid from this source, but in the case of transformer and switch oils, it is of great importance that the percentage of mineral acid be exceptionally low, so that, whereas for ordinary purposes a percentage of 0.03 in terms of SO_3 may be permitted, the percentage in the case of transformer oils must not exceed 0.01.

b. Petroleum acid may be present in the original crude or may be produced during distillation and refining. Petroleum acids develop in circulation oils during continuous use, owing to oxidation. They are very weak in their action and affect no

metals except lead and zinc; mineral oils usually contain less than 0.01 per cent of petroleum acids, but the presence of a larger percentage is not harmful as long as the percentage does not exceed 0.3 per cent in terms of SO_3 (used circulation oils).

c. *Free fatty acid* is present only in lubricating oils that contain fixed oils. The percentage of free fatty acid in a fixed oil is not objectionable as long as it does not exceed 0.5 per cent in terms of SO_3. A higher percentage of acid is permissible in certain cutting oils. A mixture of fixed oil and mineral oil will, of course, contain proportionally less of free fatty acid the greater the percentage of mineral oil.

When the content of free fatty acid is high in a lubricating oil, it has the effect of attacking the metallic surfaces with which the oil comes into contact. Metallic soaps are formed, which choke up the oil pipes and lubricating channels in the machinery. In contact with brass parts verdigris is formed. The softer metals like lead and zinc are very quickly attacked, and the effect is marked in bearings lined with white metal containing a high percentage of these metals.

When oils containing fatty oils are stored in storage tanks or cabinets that are either unlined or merely galvanized, the free fatty acid attacks the metal surface, forming metallic soaps. It has been found, however, that tin is not attacked to any degree by the free fatty acid, and for this reason all oil cabinets and oil tanks should be tinned on surfaces in contact with the oil. This also applies to other parts of the cabinets, such as oil pumps and strainers.

During continuous use, all oils containing fixed oils oxidize (air) and hydrolize (moisture), the result being the formation of free fatty acid and of sticky, gummy, varnishlike deposits, which may cause trouble.

d. *Rosin acids* indicate the presence of rosin or rosin oil which is always objectionable in lubricating oils.

Saponification Value.—The saponification value is the number of grams of potash (KOH) required to saponify the fatty (vegetable or animal) constituents present in 1,000 g. of the oil. The saponification value is therefore useful in determining the character and percentage of a fixed oil present in a mixture of fixed oil and mineral oil. When two or more grades of fixed oil are present it is difficult to identify them with certainty.

Iodine Value.—The iodine value is the number of grams of iodine absorbed by the unsaturated constituents present in 100 g. of the oil.

It has been mentioned that fixed oils have a great affinity for oxygen and that during continual use they will oxidize and form deposits. The iodine value is an indication of this tendency and is based on the fact that iodine will quickly combine with those ingredients in the oil which have a tendency to oxidize.

As might be expected, the iodine value of drying oils like linseed oil is very high, whereas the iodine value of mineral lubricating oil is very low. Below are given typical iodine values for various oils:

Drying oils, such as linseed oils	Above 170
Semidrying oils, such as cottonseed, ravison rape, fish, and whale oils	From 100 to 170
Nondrying oils, such as animal oils (except whale oil) and vegetable oils (except cottonseed and ravison rape)	50 to 100
Scotch shale oil 0.890	23
Russian mineral lubricating oils	7
American mineral lubricating oils (paraffin base)	10 to 16

The cause of the high iodine value of Scotch shale oil is the large percentage of unsaturated hydrocarbons present in it.

Oxidation and Gumming.—In order to get an idea of the tendency of lubricating oils to oxidize and gum, many tests have been devised; in one test, 1 g. of the oil is heated on a watch glass for a certain length of time at certain temperatures, after which the oil is examined. Another test measures the increase in weight, *i.e.*, the amount of oxygen absorbed and the percentage of free fatty acid formed. All such tests are of value in comparing one oil with another. The iodine value, however, appears to be the nearest approach to a correct indication of the tendency of an oil to oxidize.

Under "Color" it was mentioned that the color of an oil is due to the presence of unsaturated hydrocarbons. It is therefore to be expected that oils dark in color are more easily oxidized than pale oils, and experience has proved this to be the case. Where machinery is exposed to sunlight, *e.g.*, steam rollers and steam tractors, it has been found that red oils produce a tenacious dark-brown skin on the metal parts, whereas pale asphaltic or naphthenic-base oils have very much less tendency to form such deposits.

Frequent complaints have also been made that machine parts in engine rooms become tarnished, also the bright parts of spindle frames in textile mills, unless very pale oils are used. This tarnishing effect is very unsightly in the case of high-class machine tools. In order to avoid machine parts' becoming tarnished, it is therefore best to use pale-colored oils, either straight mineral or mixed with a small percentage of animal oil. The presence of the animal oil has a peculiar effect, making it quite easy to wipe the bright parts clean. Possibly, the free fatty acid present is helpful, preventing the film from forming, owing to a very slight corrosive action between the acid and the metal. An admixture of vegetable oil would increase the oxidizing tendency of the oil.

For oils that are used in connection with transformers and air compressors, it is obvious that they must have the smallest possible tendency to combine with the air. Circulation oils (for steam turbines, etc.) are also in more or less contact with air and therefore subject to oxidation. It would therefore seem desirable to examine oils to be used for such purposes by subjecting them to an oxidation test on lines similar to the sludging test proposed by Michie for testing the sludging tendency of transformer oils. This test is carried out as follows:

"One hundred cubic centimeters of the oil is placed in a 200-cc. flask and maintained at 150°C. for 45 hr., during which period dry air is passed slowly through the oil at the rate of 0.066 cu.ft. per hour, a piece of copper with a total surface area 4½ sq. in. being placed in the oil.

"The amount of sludge found is then determined."

Ash.—Ash is present in appreciable quantities only in lubricating oils that have been soap thickened or badly refined. Distilled mineral lubricating oils should not contain more than 0.02 per cent of ash; and for undistilled oils like steam-cylinder oils, the ash should be less than 0.1 per cent. The ash may consist of iron rust from the still, or it may be alkali from the refining.

Carbon Residue.—Oils that during use are vaporized or burnt, as is the case with all oils used for internal-combustion engines, produce more or less carbon deposit. It is difficult to duplicate these conditions in a laboratory test, but it would seem desirable to have some kind of test for the tendency to carbonize,

the results to be compared with actual practice in order to ascertain their value.

One apparatus has been suggested by P. H. Conradson. This method is a modification of his original method and apparatus for carbon test and ash residue in petroleum lubricating oils. (See *Proceedings Eighth International Congress of Applied Chemistry*, New York, September, 1912, Vol. 1, page 131; also reprint in the *Journal of Industrial and Engineering Chemistry*, Vol. 4, No. 11, November, 1912.)

Asphalt and Tar.—It is seldom necessary to test lubricating oils for the presence of asphalt and tar, except in the case of dark cylinder oils, particularly those used for superheated steam.

A distinction is made between hard asphalt and soft asphalt, the hard asphalt being the more objectionable of the two, as it will form hard, brittle carbonization deposits inside the engines.

Filtered cylinder oils contain less asphalt than dark cylinder oils and are therefore to be preferred in all such cases where carbonization ordinarily may be expected to take place.

Oiliness.—The property in a lubricant that causes it to adhere to metallic surfaces is generally referred to as its oiliness.

No means have as yet been devised by which the power of a lubricant to adhere to metallic surfaces can be directly measured; if lubricated surfaces are pulled apart, the lubricating film itself is severed, but the lubricant still adheres to both surfaces, so that it is only the cohesion of the film that can be determined in this manner. This property is of no value under fluid friction conditions, when the viscosity of the oil is the only factor of importance, but is the most important property under boundary lubrication conditions, when the film of lubricant is so thin that no part of it lies outside the range of the molecular forces which attract the bearing surfaces mutually. These molecular forces make themselves felt at a considerable distance from the surface molecules (according to Hardy, up to a distance of 0.0016 in.). The oil molecules are therefore adsorbed with a considerable force by the metal molecules of the sliding surface; they penetrate the surface to a certain depth; and, according to the greater or lesser chemical activity (content of surface-active polar bodies), they combine more or less intimately and/or cling more or less tenaciously to the metal surface molecules.

Under these conditions, the viscosity of the oil is immaterial; it is the chemical nature of the oil—its oiliness—that matters. Two oils may have the same viscosity, and the oiliness be much greater in the one than in the other. It is common knowledge that all fixed oils, or mixtures of mineral oils and fixed oils, possess greater oiliness than straight mineral oils. From the writer's experience it seems also certain that a mixture of low-viscosity distilled mineral lubricating oil and filtered cylinder stock has greater oiliness than a distilled mineral lubricating oil of the same viscosity as the mixture.

That distilled lubricating oils are improved in oiliness by the admixture of fixed oil or filtered cylinder stock may be explained by the fact that molecules of the fatty oil or cylinder stock adhere to the metallic surfaces in preference to the molecules of the distilled mineral oils; such coating of the surfaces with strongly adhering molecules explains why it is possible with blended oils to sustain almost as great pressures as if the fixed oil or filtered cylinder stock were used alone.

It is a remarkable fact that great oiliness in a lubricant is produced by the presence of a quite small amount of a "very oily" lubricant. For example, compounding a spindle oil with 6 per cent of a fatty oil produces an oil that for many purposes is just as good as if 10 per cent of fatty oil were used.

As long as there are sufficient very oily molecules present to coat the frictional surface, the oiliness cannot be much improved by further addition of the very oily lubricant.

This is brought out very clearly by experiments by J. H. Hyde (Report of Lubrication and Lubricants Inquiry Committee, 1920, pages 63 and 64) and even more so by his experiments reported in *Engineering* for June 10, 1921, pages 708–709, where it is also proved that small additions of fatty acid have a greater influence than neutral fatty oils in improving the oiliness of mineral oil.

Interesting results showing the value of fatty acids as lubricants were given in a paper read on Feb. 2, 1920, by Henry M. Wells and James E. Southcombe before the Society of Chemical Industry, London.

The author has used the addition of from 2 to 10 per cent of fatty acid in various internal-combustion engine oils and others as far back as 1908 and found the acids more active than neutral

fatty oils; only they must be used with a great deal of judgment to avoid trouble.

Experience shows that the oiliness is greatest for fatty acids, smaller for fatty oils, and smallest for mineral oils, although varying within fairly large limits inside each group.

It is now generally recognized that the oiliness of a lubricant is determined only to an insignificant degree by its physical properties but chiefly by its chemical properties or, rather, the chemical properties of its very oily constituents which need amount to only a small fraction of the bulk of the lubricant.

Extreme-pressure lubricants have been developed during the last few years and are finding an increasing use for lubrication of highly loaded tooth gears, for heavily loaded bearings, for wire-drawing, deep pressing of metal, etc.

A method of testing extreme-pressure lubricants has been developed by the Engine Testing Station at Delft, Netherlands, belonging to the Royal Dutch Shell Company. It consists essentially of four ½-in. balls in the form of a pyramid; the three lower balls are placed in a cup, into which the oil to be tested is poured. The top ball is rotated, and the cup with the three balls is forced against the top one. The cup will now endeavor to revolve, and the torque is measured.

Two standard tests are made: (1) a 1-min. test under heavy load; (2) an 8-hr. test using lower loads.

The torque during the tests and the wear of the balls are measured. The wear diagram obtained from the short-duration test is said to be of great importance for evaluating the load-carrying capacity of the lubricants.

W. J. D. van Dyck[1] after describing this test method, said that in this apparatus a good mineral oil cannot stand a much higher load than 200 lb., and a fatty oil not much more than 250 lb. An extreme-pressure lubricant on a sulphur base showed far better results, while a lubricant on a combined chlorine and sulphur base would withstand a load ten times that of mineral oil. Van Dyck emphasized that the properties of load capacity and wear measured in this manner are not conclusive for evaluating extreme-pressure lubricants in practice. Other factors, such as stability in storage and in use; the absence of corrosion on the different materials with which the oil might come into contact,

[1] *Engineer*, Oct. 11, 1935, p. 382.

both when the lubricant is fresh and when it is used for long periods; and stability against water, must all be taken into account, as in the case of normal lubricants.

Impurities.—The impurities most frequently met with in lubricating oils are dirt, glue, and water.

Dirt.—Dirt is easily detected when the oil is transparent. It is more difficult in the case of dark oils, such as cylinder oils. The best way of testing a lubricating oil for dirt is to draw a few gallons of oil from the bottom of the barrel or the tank in which the oil is stored and then strain the oil through muslin or silk cloth. Anything that remains on the cloth can be freed from oil by treatment with gasoline, and it is then generally easy enough by the aid of a magnifying glass or perhaps even with the naked eye to judge what the impurities are.

If metallic iron in the form of iron scale is present (from the steel drum or barrel), a magnet will detect it, the small particles being drawn up at the approach of the magnet; or the metallic ingredients can be identified chemically.

Cotton waste, small pieces of wood, etc., are easily recognizable, and it is not unusual for them to find their way into the oil when the barrel is being broached.

The bung should be loosened by striking the staves with a mallet, and it should never be removed by the use of an augur.

Glue.—Glue is used for impregnating the inside of wooden barrels and serves two purposes: (1) *preventing oil leakage* through the wooden staves; (2) *preventing moisture from entering the oil.*

The importance of the first-mentioned object is obvious, and the desirability of preventing moisture from entering the oil is explained in the next paragraph under "water."

Sometimes large quantities of glue are found in a barrel because the barrel has not been properly drained of the hot liquid glue during the gluing process. The glue will, however, not mix with the oil except in the presence of moisture and can always be detected easily by the consumer, when the oil is being strained before use. If the glue is not detected, the results may be disastrous, as it will cause excessive heating and wear and develop sticky deposits in lubricators, in circulation oiling systems, and in oil pipes; it will cause irregular working of lubricators, especially those having fine openings, as hydrostatic-displacement

cylinder lubricators. When such fine openings become choked, steam valves and pistons cry out for oil if the trouble is not observed in time.

Water.—Water gives an oil a cloudy appearance, and its presence is therefore easily perceived in oils, which in dry condition are transparent.

When the oil is heated to a few degrees above 212°F. it will soon become transparent, if the cloudiness is due to water; and if more than a trace of moisture is present, it will partly evaporate and partly separate out as visible drops of water at the bottom.

Mineral oils are more easily clarified than oils containing fixed oils, as the latter have a strong affinity for water and easily become emulsified.

The presence of even a trace of moisture is very detrimental in transformer and switch oils. A simple test (apart from testing dielectric strength or specific resistance) is the hot-iron test. An 8-oz. bottle is half filled with transformer oil; an iron rod, say ¼ in. in diameter, is heated for about ½ in. to a dull red heat and slowly lowered into the oil. If more than 0.01 per cent of water is present, the tiny particles of water will suddenly turn into steam with a crackling noise; if no water is present, there will be only a slight hissing noise from the oil vapors.

The presence of a slight amount of moisture in oils, other than transformer and switch oils, is not detrimental, so far as the influence of the water itself is concerned; and yet, in nearly every case where the oil is moist, more or less trouble is experienced. Ring spindles and other textile spindles rust and run warm; internal-combustion engines develop an excessive amount of carbon deposit; the pistons heat up and wear rapidly; the oil is reported to be "thinner than usual" (because the excessive heating of the oil film thins the oil); and the oil comes out of the pistons and bearings in a chocolate-colored or blackened, dirty condition.

This very remarkable effect of the presence of small amounts of moisture is explained by the fact that moisture nearly always gets into the oil through exposure of the wooden barrels to the weather. During warm and rainy weather the staves expand and absorb moisture; during nights they contract, and the effect of such alternate expansion and contraction is that moisture gets through to the inside of the staves, loosens and dissolves

some of the glue coating, and spreads it throughout the contents of the barrel. This is the most dangerous form in which glue can be present in the oil, and it is usually the glue that causes lubrication troubles, more so than the water. Wooden barrels, when in transit, should therefore preferably be covered with tarpaulins and should be stored under cover in a dry place. When barrels are stored out-of-doors from lack of space under roof, they should be covered with waterproof covering or stored on their sides; when stored on end, the moisture collects over the staves, and there is a greater likelihood of the water's getting inside than when they are stored on their sides.

MECHANICAL MEANS OF TESTING LUBRICANTS

Mechanical Testing Machines.—As the usual physical and chemical tests of lubricants do not always definitely indicate whether one oil will be more satisfactory than another for certain machines, many investigators have designed friction-testing machines with a view to comparing the lubricating properties of different oils. There is a great variety of these machines, chiefly for testing bearing oils, and they have been extremely useful in discovering important laws of friction and in comparing the efficiency of different lubricating systems. The results of such experimental work have been of interest to oil manufacturers and lubrication engineers, but from an oil consumer's point of view they are, speaking generally, of no value so far as the selection of suitable oils is concerned.

The difficulty is that the testing machine has only one bearing, usually with beautifully finished rubbing surfaces and operated under conditions of oil feed, pressure, speed, and temperature quite different from practical conditions. In most works there are such a variety of bearings that it is quite impossible to reproduce all these conditions on the one bearing of a testing machine.

The following two examples may prove instructive:

Example 1.—A certain government had a *Lahmeyer oil-testing machine,* with which all of the oils offered by various firms were tested. The oils were intended to be used on the propelling machinery of warships.

In the Lahmeyer testing machine two heavy flywheels are carried, one on each end of a shaft; the shaft is supported by a

central ring oiling bearing, which serves for testing the oil. The machine is driven by an electric motor, which can be connected to the flywheel shaft by a pin coupling. The method of testing is as follows:

The bearing is supplied with the oil to be tested. The motor is started, and the flywheel rotated at full speed—1,500 to 1,700 r.p.m. The motor is then uncoupled, and the time noted that elapses before the flywheel comes to rest.

The longer the time taken by the shaft to come to rest the better is the quality of the oil supposed to be, and this is true for *this particular bearing.*

Before the next sample of oil is tested the bearing is quickly cleaned by benzine passed through it, and it is dried out with an air current.

It will be understood that an oil manufactured to meet the conditions of a high-speed ring-lubricated bearing will give the best results when tested on this machine.

In order to convince the government in question as to the futility of testing oils in this manner, a good dynamo oil was submitted, and it was found that the shaft revolved three times as long as with the marine oil, which in actual practice gave the best results. It was obvious to everyone concerned that the dynamo oil was absolutely unsuitable for the work required.

Example 2.—One of the best oil-testing machines on the market is Thurston's machine. The machine consists of a shaft supported by two bearings; the shaft at one end has an overhanging bearing fitted with two brasses, on which the oil is tested. Suspended from the bearing is a hollow pendulum containing a spring, by means of which a certain bearing pressure may be maintained. When the shaft revolves, the oil film interposed between the shaft and the brasses causes the pendulum to swing outward, and it remains in a certain position according to the oil in use.

The less the outswing the less is the coefficient of friction and the better the oil, for this particular bearing and for the particular conditions prevailing.

When tests were carried out to find out which was the most suitable oil for shafting bearings running at a certain speed and bearing pressure, a Thurston testing machine was made to run under as nearly as possible similar conditions; it was found,

however, when testing different oils, that the coefficient of friction was the least for pure kerosene, which would, of course, be useless for the lubrication of shafting bearings.

This result will be easily understood when one takes into consideration the fact that shafting in actual practice is always more or less out of line and that the bearing surfaces are never perfectly smooth. The pressure, therefore, will not distribute itself so uniformly over the entire bearing surfaces, as will be the case with the bearing of Thurston's oil tester.

The limitations of testing machines are now beginning to be generally recognized; it is only where, as in the case of railways, a great many bearings are alike and operating under similar conditions that it seems at all worth while to attempt the construction of a testing machine; even then there is ample evidence that variations in the results obtained with the same oil in use may easily amount to 50 and rarely fall below 10 per cent.

The author feels that, from the consumer's point of view, the coefficient of friction of various oils as determined by a testing machine is not of much use; the oil that gives the least friction on the testing machine may often prove to be unsuitable in actual use.

In the foregoing no reference has been made to testing machines for testing oils for internal lubrication of steam cylinders, gas engines, etc. Not a few attempts have been made in these directions, but, as far as the author knows, the results have been of doubtful value, if not altogether misleading. It must be kept in mind that in the internal lubrication of, for example, steam cylinders and internal-combustion engine cylinders, the lubrication is nearly always imperfect and subject to so many influencing factors that it is much more difficult to reproduce the conditions in a testing machine than in the case of bearings. Besides, the value of a lubricant often becomes apparent only after several weeks or months of use; such properties as tendency to carbonize, emulsify, oxidize, etc., may become of paramount importance, as compared with the friction-reducing properties of the oil, as will be made clear later on in the various chapters devoted to the different kinds of engines.

Works Tests.—The author has come to the conclusion, and most lubrication engineers will, he feels certain, agree with him, that *the only reliable way of testing lubricants* is to test them *under*

actual working conditions, by applying them to the machinery upon which they are to be used, and watch the results.

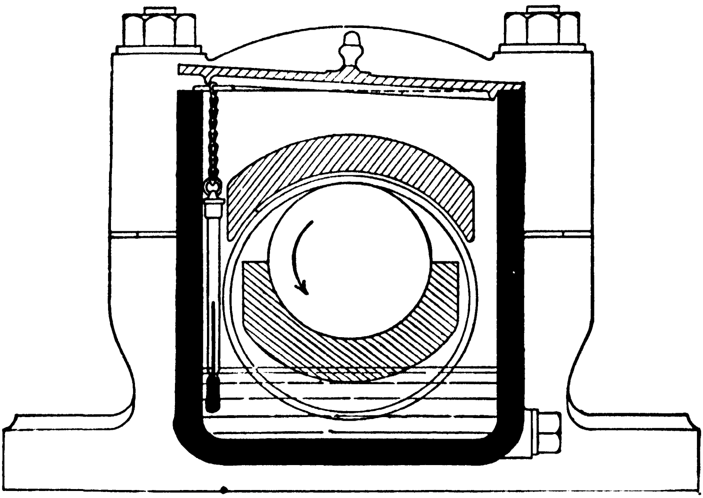


Fig. 2.—Taking the temperature of a ring-oiling bearing.

Temperature Tests.—The simplest method of comparing two oils is to compare the frictional temperature rise of typical

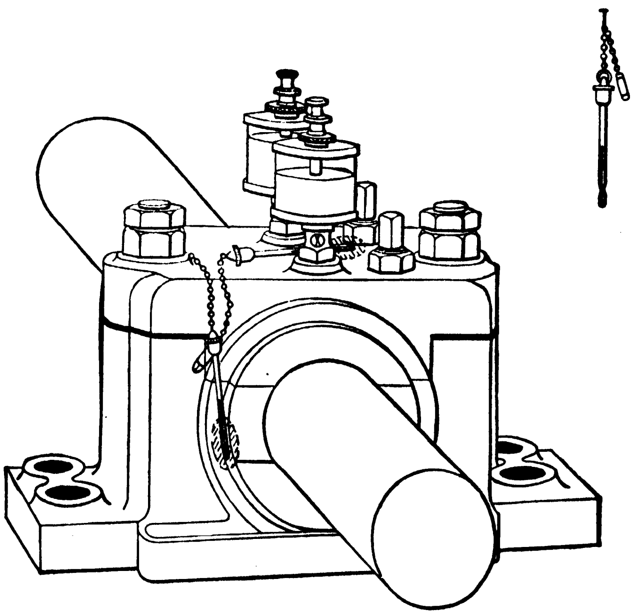


Fig. 3.—Taking the temperature of a pedestal bearing.

bearings, using first one oil and then the other. Any difference in quality or suitability between the two oils will be shown by

a different frictional rise in temperature above the surrounding air temperature. The difference in temperature between a bearing and the air close to it will remain the same, independent of the air temperature, as long as the same oil is in use.

Figures 2 and 3 show the method of taking the oil temperature of a ring-oiling bearing and a pedestal bearing. In the first case the thermometer bulb is immersed in the oil; in the second the bulb is covered with a lump of fairly stiff grease or putty, so that the bulb may be held in contact with the metal and as accurately as possible record the correct temperature.

Below is given a typical example of a temperature test on a ring-oiling bearing, a viscous oil being compared with an oil of the correct light body:

Time	Temperature of engine room, degrees Fahrenheit	Temperature of dynamo bearing, degrees Fahrenheit	Frictional rise in temperature, degrees Fahrenheit
9.45 A.M.	60	120	60
10.0 A.M.	61	121	60
10.30 A.M.	62	121	59
11.0 A.M.	Change made to	low-viscosity oil	
1.0 P.M.	63	99	36
1.30 P.M.	63	97	34
2.0 P.M.	62	93	31
3.0 P.M.	61	90	29
4.0 P.M.	59	88	29

It sometimes takes several weeks before the minimum temperature is reached, especially when there is a great difference between the two oils.

Special thermometers are used for taking spindle-rail temperatures; one method is to fix a shallow box to the rail; the bottom of the box near the rail has a long slit into which the thermometer is fixed, the bulb being pressed lightly against the rail; the box has a hinged lid, which is lifted only long enough for the temperature to be read.

Temperature tests are extremely useful for comparing oils in actual use, and the tests should be repeated from time to time with a view to checking the quality of the oils in use. If the mechanical conditions do not change, the rise in temperature

of the bearings above the surrounding air should remain very nearly constant.

In order that reliable temperature readings may be taken, quick-registering and accurate thermometers should be used. Most engineers' thermometers are sluggish and liable to be fractured when carried in the pocket or dropped to the ground. The

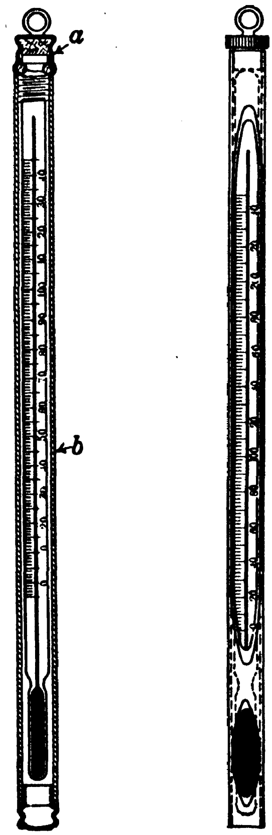


FIG. 4.—Engineer's thermometer.

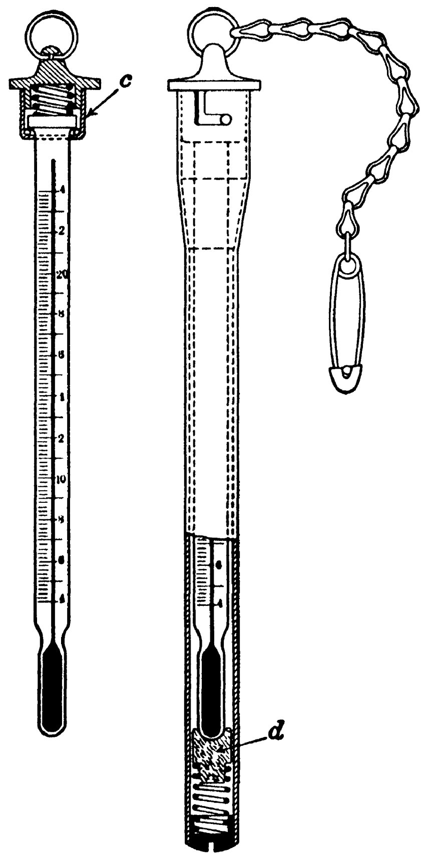


FIG. 5.—Thomsen's engineer's thermometer.

author's staff of engineers broke so many thermometers of the type illustrated in Fig. 4 that he designed a special thermometer and case, as shown in Fig. 5. The thermometer head is flexibly secured in the cap, which fits into the case with a bayonet joint, and when in position the bulb of the thermometer is kept central out of contact with the case by means of a spring pad. When the thermometer is carried in the pocket, it cannot be broken, and it is prevented from dropping out by the safety pin fastened

to the clothing. The introduction of this thermometer reduced the number of breakages practically to nil.

Dynamometer Tests.—Several dynamometers, such as Emerson's and Bailey's, are employed for measuring the power consumed by individual machines, such as spinning frames, but only for small horsepowers.

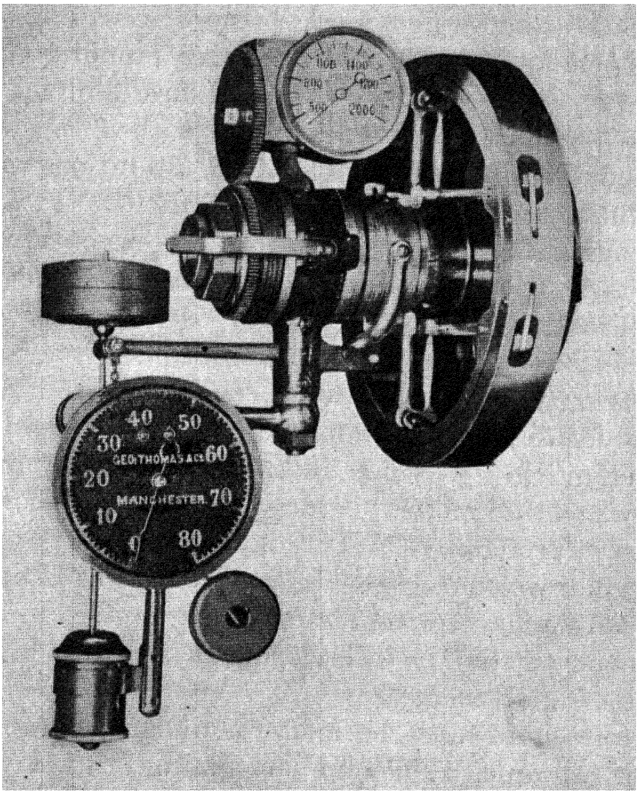


FIG. 6.—Emerson's dynamometer.

Emerson's machine (Fig. 6) is the first instrument that was ever used in the oil business for the purpose of showing the value of good lubrication. It is fixed to the driving shaft outside the loose pulley. The pull of the belt goes through the arms, which pull back levers, just like an ordinary weighing scale, and the pointer shows the number of pounds exerted. The diameter of the wheel is 2 ft. The speed is measured in r.p.m., and the horsepower is calculated from the formula

$$\text{Horsepower} = \frac{\text{net weight} \times 2 \times \text{r.p.m.}}{33{,}000}$$

These instruments are so finely adjusted that if two or three spindles are stopped by hand, the pointer immediately registers the increased friction.

Electrical Tests.—Where a machine or a group of machines is driven by electric motors, it is a simple matter to record the power consumption. But apart from the electrical measurements (volts, amperes, kilowatts or B.t.u. per hour, as the case may be) it is desirable or necessary to record, as with the spinning-frame tests, the temperature and relative humidity of the air; the speeds of motor, shafting, and machines; and the frictional temperatures of important bearings, all with a view to getting as complete indications as possible of the alterations caused by a change in lubricants or lubricating methods.

Steam-engine Tests.—To record the power consumption of a factory or mill by means of indicator diagrams taken from the engine requires extreme care for the purpose of making a comparison between two sets of lubricating conditions. The load always varies, even under the most ideal conditions; the governor is continuously altering the amount of steam admitted, and diagrams taken quickly after one another may differ appreciably.

The only accurate method is to take a great number of indicator diagrams (preferably on Tuesdays, Wednesdays, or Thursdays) at regular working intervals, say every 10 or 15 min. during, say, 4 working hours; the indicator-pencil motions may be fitted with magnets, so that by the closing of a switch all diagrams can be taken simultaneously.

An accurate note must be made of machines stopped in the mill; if, for example, a machine consuming 8 hp. is stopped for half an hour, the equivalent value over the 4 hr. is 1 hp. If the values of all such stoppages are added together and amount to 17 hp., and the average indicated horsepower, calculated from all diagrams, is 805 hp., then it may be assumed that the mill would consume an average of 822 hp. if all the machines had been working continuously.

If on the comparative test, say 3 months later, the average power with other oils works out at 742 hp. and the value for machines stopped is 14 hp., then the comparative power value with the new oils is 754 hp., which represents a saving of 68 hp., assuming that the conditions as regards temperature, relative humidity, etc., are similar.

Gas-engine Tests.—The usual particulars should be recorded; the gas consumption can be taken when a gas meter is installed and should be reduced to a basis of 32°F. gas temperature and 28 in. mercury barometric pressure, so that the amounts of gas consumed on both tests may be made comparable. The temperature and pressure of the gas should therefore be recorded, also the calorific value of the gas. The temperature of water inlet and outlet for the water jacket, temperature of intake air, the position of air intake on engine (if variable), and the number of actual explosions per minute should be recorded, as they may prove important in comparing the results of two sets of oils.

Where the gas consumption cannot be recorded, indicator diagrams may be taken, from which the power consumption can be calculated.

"Free-revolution" Tests.—An approximate comparison between two sets of lubrication conditions may be made by running a number of transmission shafting, countershafting, and machines *idle* at normal speed and then suddenly shutting off steam, gas, electricity, or whatever moving power is employed. The prime mover (steam engine, gas engine, electric motor, etc.) will continue to operate for a certain number of revolutions and for a certain length of time. By improving the lubrication, the prime mover will run for a longer period and a greater number of "free revolutions" before it comes to a standstill. This method is not very scientific but is simple to carry out and often useful.

Similar effects are noticed on spinning frames; with improved lubrication they run for a longer time when the belts are thrown on to the loose pulleys. In the same way, the driver of a hoisting engine finds that he opens his throttle later and closes it earlier when the lubrication of valves and cylinders is improved. It will generally be found that engine attendants or machine operators who have handled their machines for a long time have some way of judging the state of lubrication efficiency. They know at once if there is a change, although many of them do not know how to express themselves in technical terms.

General Remarks.—As to selecting a suitable part of a factory for a test, it is difficult to give general rules. It will often be found that the engineer of an up-to-date works has a favorite piece of plant on which he makes all his trials and tests. Such a place should always be given preference, provided, of course,

that it meets all requirements, as the engineer will be more familiar with the running of such machinery and will the more readily notice any improvement achieved by changing the lubricant.

Where it is possible, a compact group of machines should be chosen. It is desirable that the group be compact, so that the whole of the plant may be under observation of the operator while running; the stoppage of a machine, the breaking of a belt, or the heating of a bearing can be seen at once, a note made of the time when the machine is put out of action, and allowance made for it in the final results.

It must not be forgotten that a considerable time must usually be allowed between two comparative tests, to ensure that conditions with the new lubricants in use have become uniform. Where speeds are high, and both sets of oils are pure mineral in character, a few weeks will be sufficient; but where speeds are lower and pressures heavier, and particularly if the oils in the first set are compounded and in the second set straight mineral, or if there is a great difference in viscosities, the author has found that the change in power consumption may easily take three months to be fully accomplished.

CHAPTER VI

THE LAWS OF FRICTION

Without friction, life in the various forms in which we are acquainted with it would exist only for a very short time. Any moving mass would retain and continue its motion. If it were sliding down an incline and accelerating, it would reach another incline and rise to a certain height, then move to another position at the same height above sea level, and continue without ever coming to rest.

Everything except the solid rocky formations would start sliding. Towns and cities would be swept away with the country; steamers on the open sea, at the moment friction ceased to be, would not be able to accelerate or decrease their speed, as the friction between the propeller and the water and between the particles of water themselves would be nonexistent. Sailing ships would be in the same plight, as the wind would have no effect on the sails. Locomotives would not be able to move, as there would be no rail friction.

Friction may be defined as the resistance created by the surface of one body moving over that of another. If no lubricant is introduced between the surfaces, the friction may be termed "solid." If there were nothing but solid friction, very little machinery could be kept in operation: fast-going steamers and railway expresses would be unknown; and only the crudest forms of slow-running machinery could be operated.

Solid Friction.—All surfaces are more or less rough; even surfaces that are well machined and polished show under the microscope small projections and depressions. It is the interlocking of these minute projections that cause solid friction when two unlubricated surfaces are pressed together and move relative to one another.

When the rubbing surfaces are very smooth and in intimate contact, an additional resistance to motion is created by adhesion between the surfaces caused by molecular attraction. This

adhesive force is shown by Johnson's Swedish limit gauges used in many engineering works. When two or more of these gauges are brought into close contact, they adhere with a force several times that of the atmospheric pressure, and it is difficult to slide one surface over another, notwithstanding the absence of external pressure. Speaking generally, the laws of solid friction are as follows: The frictional resistance with solid friction is

1. Directly proportional to the total pressure between the surfaces.
2. Independent of the rubbing speed of the surfaces at low speeds but decreases at very high speeds.
3. Independent of the areas of the surfaces.
4. Dependent to a considerable extent on the roughness and hardness of the surfaces.

These laws apply whether the motion is rolling or sliding; they apply, therefore, also to ball and roller bearings.

That the friction decreases at high speeds is well illustrated by the greatly diminished brake effect of automobile brakes at very high speeds. The action of the brakes may become so reduced that it may not be possible to regain control of the car when going down a steep hill.

Contaminated Surfaces.—It is an important fact that surfaces are never perfectly clean. Chemically clean surfaces soon abrade and weld themselves together when rubbing over one another; fortunately, all surfaces are covered with what may be called contamination films of a more or less greasy nature; these films are due to the action of air, moisture, dust, and impurities on the surfaces, and they help to some extent in preventing abrasion—at any rate under low-pressure conditions—in fact, they act very much like thin lubricating films. Archbutt and Deeley mention the following experiment to illustrate the effect of contamination:

A smooth file passed over a freshly prepared clean surface will be found to cut well even when only gently pressed against the metal; but if the hand be passed over the metallic surface, the film of grease therefore deposited will so lubricate it that considerably greater pressure on the file is now needed to cause it to cut.

Owing to the surface irregularities of the rubbing surfaces, wear takes place, the softer surface being more rapidly abraded than the harder. The wear and friction are much less for hard and smooth than for soft and rough surfaces.

Surfaces of exactly the same material are more inclined to seize and weld than dissimilar surfaces; this is the reason why materials of different hardness and composition are used for all rubbing surfaces, *e.g.*, a steel journal in a white-metaled bearing and soft cast-iron piston rings against a harder cast-iron cylinder.

Although the friction between solid surfaces is independent of the area in contact, the wear is obviously the greater the smaller the area, because of the greater pressure per square inch.

By the introduction of a suitable third medium between the frictional surfaces, a medium that may be solid (such as graphite, talc, or white lead) or of an oily nature (such as lubricating grease or lubricating oils), the solid friction may be partially or wholly eliminated, and, with the latter mediums, replaced with "soft—solid" or fluid friction. Roller bearings and ball bearings are excepted in this connection.

Fluid Friction.—The object of all lubrication is that the lubricant should attach itself to the rubbing surfaces and form a film between them, which, under the conditions of speed, pressure, and temperature prevailing, will not be squeezed out but will keep the frictional surfaces apart. This object is not often attained, except in high-speed bearings, *e.g.*, stream-fed bearings lubricated by a circulation oiling system, as in steam turbines and high-speed steam engines; many ring-oiling bearings; Michell bearings; and Nomy bearings.

In bearings thus perfectly lubricated the "rubbing" surfaces never touch one another, and the friction is entirely dependent on the lubricant. The laws governing fluid friction are totally different from the laws for solid friction and may be summarized as follows: The frictional resistance with fluid friction

1. Is independent of the pressure between the surfaces.
2. Increases with speed of rubbing surfaces.
3. Increases with area of rubbing surfaces.
4. Is independent of the condition of the rubbing surfaces, or the materials of which they are composed.
5. Depends entirely on the viscosity of the lubricant at the working temperature of the oil film.

If the frictional resistance is F, and the total pressure between the rubbing surfaces P, then the friction equals P multiplied by the coefficient of friction C, *i.e.*:

$$F = C \times P$$

and

$$C = \frac{F}{P}$$

The coefficient of friction for unlubricated surfaces ranges from 0.1 to 0.4, but with fluid friction the coefficient of friction ranges from 0.002 to 0.01 according to the viscosity of the oil. It is therefore worth while, wherever possible, to design bearings so that fluid friction, or a condition approaching fluid friction, can be brought about.

Boundary-lubricated Surfaces.—Under conditions of low speed and high pressure it is impossible or extremely difficult to obtain perfect film formation, nor is it possible in the great majority of bearings, which are not stream fed but supplied with only a limited amount of oil per minute, to produce anything approaching perfect film formation. The surfaces accordingly are in an imperfectly lubricated or semilubricated condition—boundary lubrication—for which the coefficient of friction will range from 0.01 to 0.10 according to whether the surfaces are very poorly lubricated—approaching the condition of unlubricated surfaces—or fairly well lubricated—approaching the condition of perfectly lubricated surfaces.

There Are No Definite Laws Governing the Lubrication of Boundary-lubricated Surfaces.—The frictional resistance is composed partly of solid friction and partly of fluid friction, and the more the solid friction predominates the more important is the property known as oiliness, and the less important the viscosity of the lubricant. The object of lubrication of such surfaces is to make the best possible compromise between reduction of wear and reduction of fluid friction. For conditions of low pressure and high speed, the reduction of fluid friction is usually the most important point to consider and demands *low-viscosity oils* of great oiliness; whereas for conditions of high pressure and low speed, the reduction of wear must be given prime consideration and therefore calls for viscous oils of *great oiliness.*

In ball and roller bearings the friction is usually not influenced by lubrication and is lower than the friction in even the best lubricated plain bearings.

On p. 85 are given approximate values for the coefficient of friction for the sake of comparison.

Condition of surfaces	Coefficient of friction	
	Range	Average value
Unlubricated or very poorly lubricated surfaces	0.1 to 0.4	0.16
Boundary-lubricated surfaces	0.01 to 0.10	0.03
Perfectly lubricated surfaces	0.002 to 0.01	0.006
Surfaces in rolling contact:		
Ball bearings	0.001 to 0.003	0.002
Roller bearings	0.002 to 0.007	0.005

Static Coefficient of Friction.—The values given above for the coefficient of friction are the kinetic values, applying to surfaces in motion. When surfaces have been at rest for some time, the oil film is more or less completely squeezed out, and a certain amount of metallic contact takes place. As a result, the starting effort, when the surfaces are again brought into motion, is much greater than the running effort; in fact, the static coefficient of friction usually approximates the values for solid friction.

When the speed of the rubbing surfaces is very low, the kinetic coefficient of friction may be even higher than the static value, as there is added to the solid friction the resistance caused by the presence of a lubricant, it being understood that the speed of rubbing is too low to allow the lubricant to produce any appreciable separation of the rubbing surfaces. As the speed increases and the lubricant begins to produce a film, the solid friction quickly decreases, and the kinetic coefficient of friction is likewise reduced, until perfect film formation is brought about.

The high values for the static coefficient of friction explain the great effort often required to start engines or machinery from rest and form one of the chief reasons why ball and roller bearings are used, as with surfaces in rolling contact there is practically no difference between the static and the kinetic coefficient of friction.

The static coefficient of friction will obviously depend on

1. *The condition and hardness of the surfaces,* being lower for hard and smooth surfaces than for soft and rough surfaces.

2. *The pressure between the surfaces;* the greater the pressure the more effectively is the lubricant squeezed out.

3. *The length of time that the surfaces have been at rest;* the longer the time the greater chance has the pressure of displacing the lubricant.
4. *The nature of the lubricant.*

Solid lubricants like graphite are not displaced, so that in bearings lubricated entirely by solid lubricants the static and kinetic coefficients of friction (within reasonable limits) are very similar. Semisolid lubricants cannot be entirely displaced by pressure during a period of rest; this is an advantage as compared with oils which occasionally may be of importance. Mineral oils are almost completely displaced, but experience proves that fixed oils or mineral oils compounded with fixed oil or oils containing colloidal graphite leave a better film in between the surfaces and that therefore the static coefficient of friction with the latter oils is considerably less than with straight mineral oils. As a result, not only is the starting effort reduced but also the wear caused by metallic abrasion during the initial moments of starting.

Temperature and Character of Frictional Surfaces.—Bowden and Ridler (Laboratory of Physical Chemistry, Cambridge) have shown that the temperature at the interface between sliding metals may reach a very high value, say exceeding 1000°C., with moderate sliding speeds and loads in the case of polished metals.

They repeated the experiments with various lubricants under boundary-lubrication conditions and again found high surface temperatures. For example, with a polished metal surface lubricated with Castrol XL and running smoothly with a low coefficient of friction, a surface temperature of over 600°C. was recorded—at the sliding surface—and yet the mass of metal was at room temperature, and there was no evidence of heating.

The results have an important bearing on the theory and practice of lubrication. The high local temperature may cause decomposition and volatilization of the lubricant and is thus an important cause of the breakdown of lubricating oils.

Bowden and Ridler's experiments throw some light upon what engineers call "skin." We talk about bearings or engine cylinders' developing a surface skin, a good working surface, a mirror-like surface, etc.; we know that every change in the lubricating conditions (changing oil or reducing the feed, etc.) alters the skin; that if this change takes place too suddenly, the skin may break, and trouble result.

It is evident that if the microscopic surface irregularities are subject to temperatures of the magnitude recently referred to, structural changes take place in the bearing surfaces *until a surface skin has been developed;* and as this obviously takes time, every change in oil or lubricating conditions must be made with reasonable care and precaution.

When during operation a surface skin is formed, this skin is very valuable, as it will sustain a much higher load than the normal load under which it was formed. Once such a skin is broken, it is important that it, or the oil film, be of such a character that it easily re-forms, and this will, of course, depend upon the oiliness of the lubricant (see page 66) and the character of the metal surfaces.

Graphoided surfaces which are produced when using lubricants mixed with colloidal graphite also appear to possess this character because the graphite, when embedded in the pores of the metal, cannot be squeezed out or easily displaced; and as the colloidal graphite has a great affinity for oil, the oil film will rather readily re-form over a graphoided surface.

CHAPTER VII

LUBRICATING APPLIANCES

The main types of lubricators and lubricating appliances are described under "Bearings." It will carry the author too far to elaborate further on the many types and constructions of lubricators in existence; he hopes that sufficient is said under "Bearings" to convey his views on the merits or demerits of the various principles involved.

As, however, mechanically operated lubricators are coming much into prominence, and as the author has taken a particular interest in these appliances, he feels that a critical review of the main types may prove useful.

Mechanically operated lubricators are now widely used for delivering a small or moderate supply of oil automatically and at a uniform rate of feeding, against a pressure ranging from a few to as much as 1,000 lb. per square inch.

Mechanical lubricators are used for feeding oil to the cylinders and valves of steam engines and air compressors; the cylinders and bearings of gas engines, kerosene engines, semi-Diesel engines, and Diesel engines; the piston-rod glands of certain ammonia compressors; certain large and important bearings which for some reason or other must have the oil forced in under pressure to prevent wear; etc.

In order to analyze the merits or demerits of the very numerous types of mechanically operated lubricators, some of the important features will be discussed as follows:

Sight feeds.
Pump plungers.
Valves.
Types of drive.
Feed adjustment.
Heating arrangement.
Strainer.
Check valves.

Sight Feeds.—From this point of view, mechanically operated lubricators may be classified as follows:

1. Those without sight feeds.
2. Those with sight feeds on the suction side of the pumps.
3. Those with sight feeds on the discharge side of the pumps.

Mechanically Operated Lubricators without Sight Feeds.—The Mollerup (so called after the inventor, a Danish engineer) mechanically operated lubricator is the most widely used lubricator of this type in Europe. A large-diameter plunger is slowly forced into a cylinder filled with oil by means of a ratchet actuating motion combined with a worm-gear drive. The oil thus driven out is passed through piping to the engine.

When the lubricator is being filled, air may be drawn into the cylinder, so that the lubricator does not start feeding immediately the engine starts, and lubrication difficulties may therefore arise before the lubricator starts to discharge the oil.

Owing to the absence of sight feeds, irregular working of these lubricators, such as leakage past the pump plunger, is not always observed in time to prevent trouble.

Some American mechanically operated lubricators have oil blinkers in the discharge line which act as the equivalent of sight feeds; they blink every time that oil is forced through but do not indicate the actual amount of oil passing.

Other makers put two-way test cocks in the delivery pipes. When the handle of these cocks is turned to a horizontal position, the oil is delivered out through a test pipe into the atmosphere under no pressure; it is assumed that when the handle is turned vertical, the same amount of oil will be fed to the engine against pressure. If, however, the pump is not efficient, or if it is out of order, this will not be the case; less oil will be forced to the engine than is indicated by the test cock.

In a multiple-feed, mechanically operated lubricator of this type, if one feed is choked and the others are working normally, it is impossible to locate the defective pump until the part of the engine supplied gives clear evidence of the lack of lubrication.

Mechanically Operated Lubricators with Sight Feeds on the Suction Side of the Pumps.—Some mechanically operated lubricators of this type (Fig. 7) have a container from which the oil is fed by gravity through sight feeds; the oil feeds are controlled by adjustable needle valves, and whatever oil drops into

the pumps is forced to the engine, less possible leakage past the plungers.

The disadvantage of these lubricators is that the oil feeds irregularly, because of variation in oil level and oil temperature. Furthermore, dirt is liable to choke up the needle valves and cause erratic oil supply. As the oil feeds are started and stopped by hand, these lubricators are not entirely automatic in action.

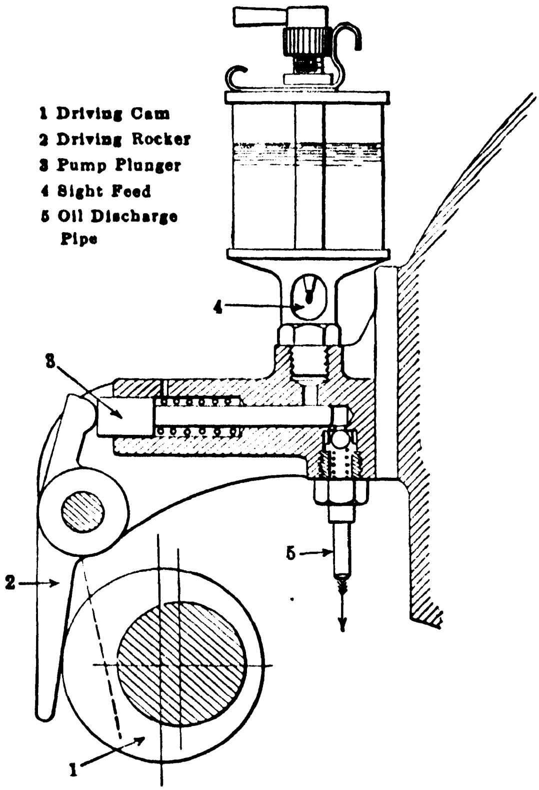


FIG. 7.—Mechanically operated lubricator with gravity sight feeds.

Other mechanically operated lubricators, although they have the sight feeds on the suction side of the pumps, are fully automatic in action, the oil feeds starting and stopping with the engine. One type of these lubricators (Fig. 8) has a single plunger which on the suction stroke draws oil through a sight feed glass filled with water; on the delivery stroke the suction valve closes, and oil is forced out through a spring-loaded delivery valve. One important drawback to this arrangement is that the water in the sight-feed glass gradually disappears and is replaced

by oil; this occurs even if a suction valve be placed below the glass, as it cannot be spring loaded; the author can see no virtue in the sight-feed glass's not being under pressure. Sight-feed glasses

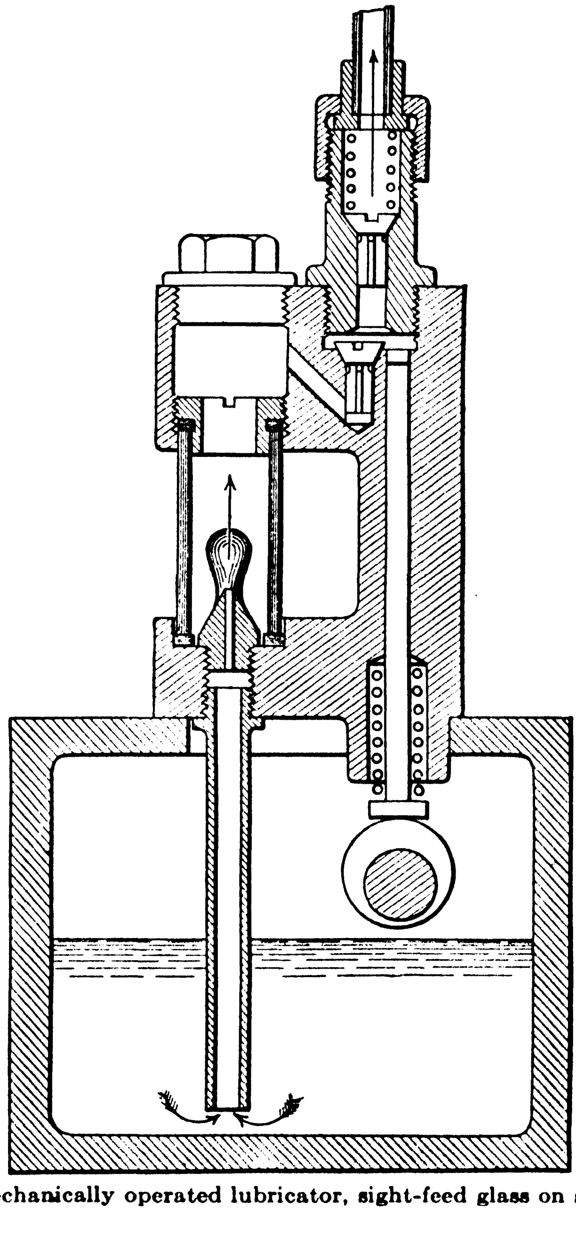


FIG. 8.—Mechanically operated lubricator, sight-feed glass on suction side.

seldom break because of internal pressure; they are either knocked to pieces, or they are fractured because of excessive strains set up when being placed in position. If the sight-feed glass is

broken, the oil feed stops, as air is sucked into the sight feed in place of oil.

All water-filled sight-feed glasses are liable to be fractured in the cold, if the water freezes. This is prevented by adding ordinary salt or glycerin to the water.

With most lubricators, which have the sight-feed arrangement on the suction side of the pumps, one cannot be certain that the true oil feed is shown. If the pump plunger leaks on the delivery stroke, some of the oil will leak back to the oil container; this cannot easily be observed, and if the leakage is appreciable, it means that more oil passes through the sight feed than is actually discharged by the pump to the engine.

Some lubricators have "dummy sight feeds." One plunger pumps the oil through a sight feed, while a similar plunger pumps *what is believed and hoped to be* a similar amount of oil to the engine; the oil drops through the sight feed back to the oil container. Cases have occurred where one plunger was pumping oil merrily through the sight feed while the corresponding plunger was air locked. Strange to say, thousands of such lubricators have been sold, and engineers have not even taken the trouble to ascertain whether the sight feeds were true sight feeds or merely dummies.

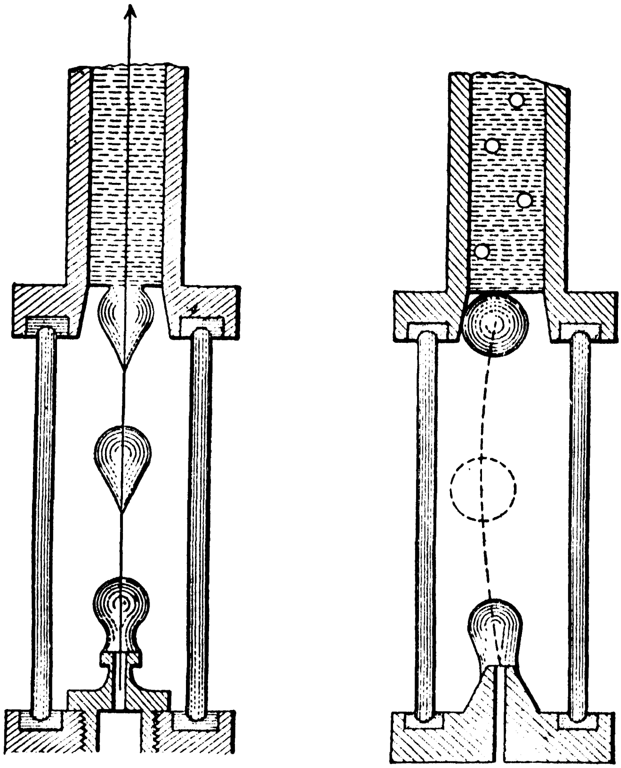
Several types of lubricators have two plungers for each oil feed. A measuring pump draws the oil from the container and discharges it under low pressure through a sight feed, whence it is sucked into the delivery-pump chamber and discharged through a check valve to the engine.

Instead of two separate plungers, a two-diameter plunger is sometimes used, the small-diameter part acting as the discharge plunger. If there be any leakage from the discharge plunger, the oil can generally be seen filling up in the sight feed, and steps can be taken to rectify the trouble. With a two-diameter plunger properly constructed, *all* the oil passing through the sight feed is forced to the engine—never less, as with leaky single plungers.

Mechanically Operated Lubricators with Sight Feeds on the Discharge Side of the Pumps.—Sight feeds that show the oil in the form of drops rising through water are true sight feeds, as they show the oil after it has left the pump and is actually on its way to the engine; it cannot go anywhere else.

Figures 9 and 10 show a cylindrical sight-feed glass, and Fig. 11 a single bull's-eye sight-feed arrangement; the former sight feed will stand 300 to 400 and the latter 800 to 1,000 lb. per square inch quite safely, when well made.

The glass in Figs. 9 and 10 has both ends rounded and ground by a circular grinder, so that there are no sharp edges, whence fractures might emanate.



FIGS. 9–10.—Sight-feed glass under pressure.

In a dark engine room it may be difficult to see the oil feed in the bull's-eye shown in Fig. 11, so a better arrangement is to have a double bull's-eye with glasses both front and back. To keep the oil drops away from the glass it is good practice to have a climbing wire inserted in the nozzle from above (Fig. 11); the oil drops form, move up the wire, and unite with the oil at the top without removing any water; when there is no wire (Fig. 10), the drops wobble up through the water and usually lean against a corner, each drop enclosing and carrying away with it a small globule of water, so that the glass soon fills up with oil; this is avoided by having a climbing wire, as shown in Fig. 9.

Another useful feature is shown in the shape of the nozzle (Fig. 9), this being narrow below the head. This prevents oil drops from sagging and creeping down the side of the nozzle and smearing the sight-feed glass, as in Fig. 10.

A third point of importance for keeping the water in the glass is a spring-loaded check valve below the nozzle; if this valve is not loaded, it "floats" after the delivery stroke has been completed; and if it is not seated at the beginning of the suction stroke, a little water may be sucked into the mouth of the nozzle; the result is that the glass slowly fills with oil.

In very cold weather, steam-cylinder oil becomes very sluggish; the oil drops become bigger, and even with a climbing wire, etc., the drops are inclined to take "pinpricks" of water away with them and slowly empty the glasses of water.

If the pump is a good one and will pump water, a simple way of driving out accumulated oil from a sight glass and replacing it with water is to pour a small quantity of water into the lubricator container gradually, until the water begins to make its appearance at the sight-feed nipple in place of oil. Then add a little more, say an eggcupful or what seems necessary, and the water will be pumped up by the action of the lubricator, refilling the glass and driving the oil out. If the engine can be stopped, the proper method is to uncouple and clean the glass and fill up in the usual way. The method described is, however, useful where an engine runs continuously.

Many engineers appear to be under the impression that a mechanical lubricator pumps oil only when a drop rises in the sight-feed glass. This is, of course, erroneous. Let us assume that it takes 10 strokes of the pump for one drop to rise through the glass; then for every stroke of the pump, the drop forming on the nozzle grows in size with a quantity equal to one-tenth drop; but as the glass is full of water, and the oil pipe leading to the engine completely filled with oil right to the check valve fitted at its extreme end, it must be clear that for every stroke of the pump one-tenth drop is forced into the sight glass at the nozzle and one-tenth drop is simultaneously discharged at the other end through the check valve. When the pump has made 10 strokes, the drop of oil formed on the nozzle becomes sufficiently large to overcome by its floating power its adhesion to the nozzle; the drop then rises, which simply means that

it changes its position in the sight-feed glass, moving from the nozzle up to the top of the glass; this movement does not in any way affect the discharge of oil from the check-valve end of the oil pipe, which continues to be one-tenth drop every time the pump plunger completes its delivery stroke.

Pump Plungers.—These should not be too large in diameter, as then the pump strokes have to be very short and easily become irregular. Two-diameter plungers are advantageous, as the

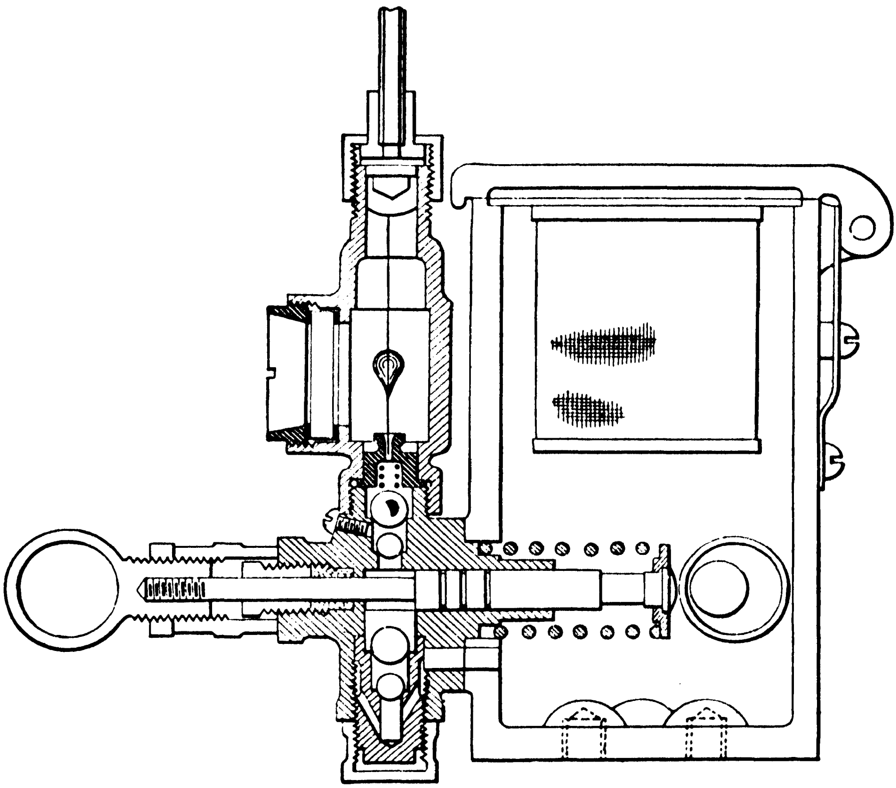


FIG. 11.—Mechanically operated lubricator with bull's-eye sight feed.

difference between the two diameters (see Fig. 11) can be made very small, say $\frac{1}{64}$ in. ($\frac{1}{4} \times \frac{17}{64}$ in.); if the plungers have to operate at high speed and must supply only a small amount of oil (*e.g.*, Diesel-engine cylinders), the stroke will still be perceptible, whereas with single plungers, $\frac{1}{4}$ in. diameter, it would be well-nigh impossible to adjust the stroke to the required length *and maintain it with certainty.*

Pump plungers should preferably not operate vertically with the oil below them, as they then easily become air locked,

and it is difficult to let the air out. Plungers should either operate horizontally or, if vertical, should have the oil above the plunger discharge end.

Outside plungers with packings should be avoided, as, if the plungers get scored, the leakage is difficult to overcome. It is better to have plungers inside the oil container and sealed by the oil; if they are hardened and ground to a good sliding fit, they will pump against considerable pressure with no or only slight leakage.

It is bad practice to have two horizontal plungers operating together on opposite sides of the container and firmly connected; it means that when they are a good fit, it takes great force to move them, as it is impossible to drill the pump cylinders in perfect alignment. Such a plunger arrangement causes excessive strain and wear of the driving mechanism.

Valves.—Most lubricators have single suction and delivery valves. If a valve becomes inactive by a piece of dirt's getting on to the valve seat, the lubricator may stop feeding. The author strongly recommends two suction and two delivery valves, so that one valve will act while the other is given a chance to get free of the dirt. The second delivery valve should be spring loaded to secure prompt closing. Spring-loaded suction valves are unsatisfactory, as the springs have to be very weak indeed, if they are not to interfere with the pump action on the suction stroke.

The valves should be easily accessible—the suction valves in particular. Figure 11 shows one method of placing the suction valves in a detachable cage. The pump should preferably be capable of freeing itself from air. With a spring-loaded delivery valve it becomes necessary to let the air out, in case of an air lock; this may be done, as shown in Fig. 11, by having a small air vent between the two delivery valves. This is opened, until all air is driven out, and oil appears at the vent; it is then closed, and the oil, having already passed the bottom valve, will force open the top valve.

Some pumps do not have suction valves but suction ports, which are uncovered and closed by the movement of the plunger. A complete vacuum is created on the suction stroke, and, when the suction port is uncovered, oil is sucked in; but with viscous oils like steam-cylinder oils, the pump motion must be very slow,

to ensure that the pump draws in a full charge of oil. A few lubricators have no valves at all but control the oil inlets and outlets by plungers very much like a piston-valve arrangement in steam engines; this arrangement requires most excellent and accurate workmanship to give satisfaction for high-pressure conditions. Whatever the valve arrangement may be, it is always desirable that the suction passages be as short and wide as possible (to avoid wiredrawing of the oil) and that the plungers operate with small pump-chamber clearance.

Types of Drive.—The principal methods of driving mechanical lubricators are

Lever drive.
Rotary drive.
Worm-gear drive.
Spur-gear drive.
Ratchet drive and ball or roller-clutch drive.

Lever Drive (Fig. 12).—The plunger is operated by a rocker, which gets its motion from some part of the engine, *e.g.*, the half-time shaft on a gas engine (Fig. 171, page 465). In this way the movement of the plunger can be made to synchronize with the piston movement, and the oil injected at a definite movement in the cycle.

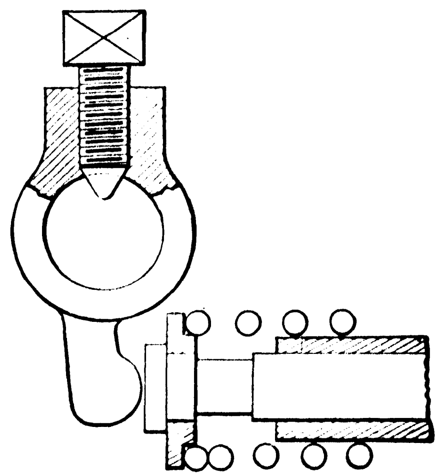


FIG. 12.—Lever drive.

In large, slow-speed, long-stroke steam pumping engines, the oil can in this way be forced into the steam just at the moment when it is required. It must be noted, however, that such timed injection of the oil can take place only in lubricators that pump oil alone and not oil and air, as do most lubricators in which oil drops through a sight feed into the delivery pump. If air gets pumped into the oil pipes, it has a cushion ing effect, and oil is discharged only when the back pressure is at its minimum.

Rotary Drive.—The lubricator shaft has a driving pulley outside the container; the shaft revolves and may, by means of a

cam, actuate the plunger. Obviously, this form of drive can in this way be adapted to time the injection of oil from the various plungers, by suitably spacing the cams on the lubricator shaft.

In most lubricators the cams do not actuate the plungers direct, as in Fig. 11, but by some intermediary mechanism, which in the majority of cases is rather unmechanical. The most common form is that of a cam revolving eccentrically between two jaws

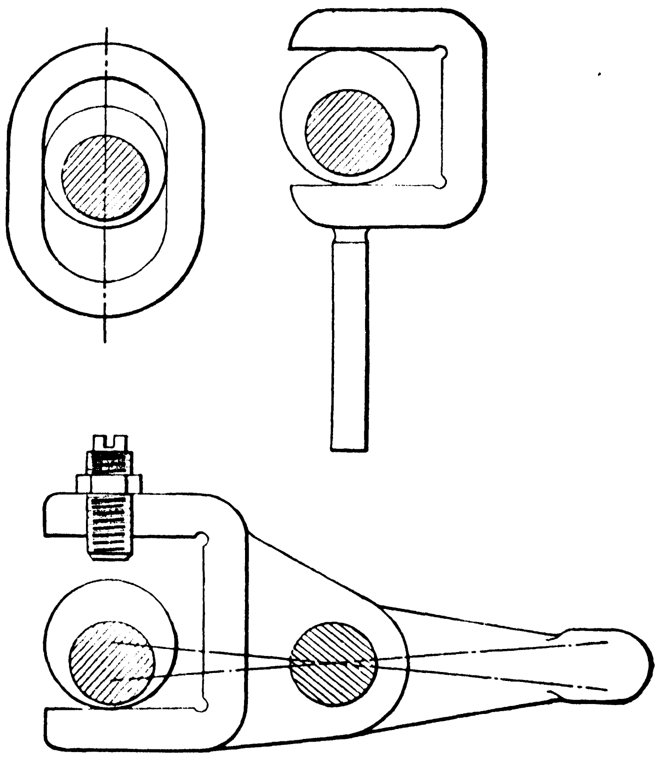


FIG. 13.—Cam motions.

or inside a slot, as indicated in Fig. 13, but a cylindrical surface does not wear well with a flat surface; the result is therefore more or less rapid wear; such motions fairly soon develop considerable backlash, which increases the wear. Figure 13 shows one method of preventing wear with a cam drive; the cam has a loose roller, which, when pressed against the plunger head by the cam, remains stationary during the delivery stroke; the cam revolves inside the roller, and, as it is well lubricated, there is no wear whatever or any side pressure on the plunger.

Worm-gear and spur-gear drives are used for operating lubricators on high-speed engines or machinery, so that the pump plungers may be made to operate at a comfortable speed and with fairly long strokes.

Ratchet drive and ball or roller-clutch drive is used when the motion is taken from some reciprocating part of the engine, *e.g.*, one of the valve rods on a steam engine (see Fig. 14). Ratchet drive is usually preferable to clutch drives, except at low speeds,

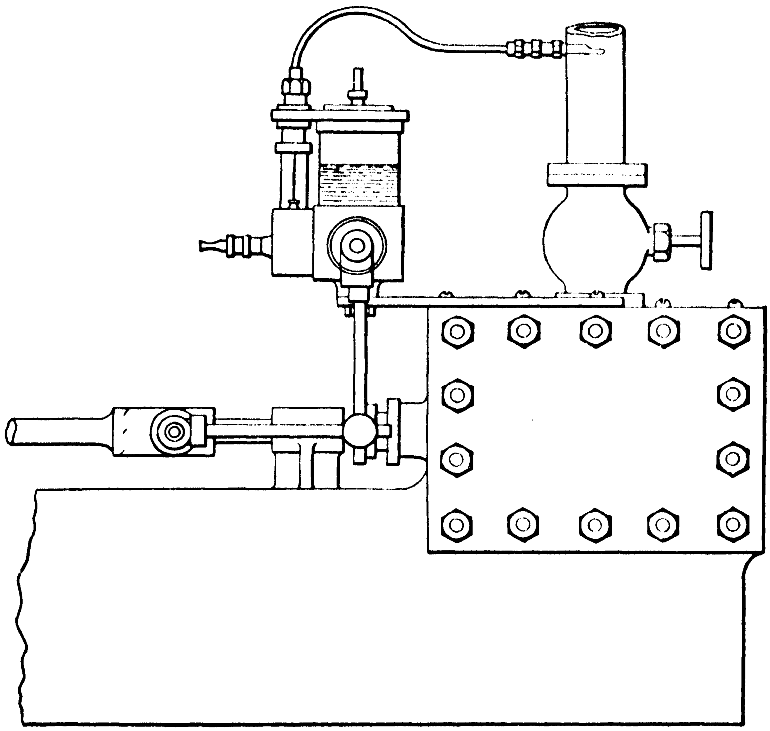


FIG. 14.—Ratchet-drive arrangement.

when there may not be much to choose between them. At high speeds, the balls and rollers in clutches wear out the casings, and slipping begins, with the too frequent result that the lubricator stops working.

High-speed ratchet drives must be carefully designed; the ratchet wheel should be made of casehardened tool steel and screwed on to the shaft in such a manner that the motion tends to keep it in place. The driving as well as the backlash pawls should be made very light, preferably of thin folded steel plate, which presses only lightly against the teeth in the ratchet wheel;

heavy pawls, due to inertia forces, do not act promptly, unless backed by powerful springs, in which case rapid wear takes place. The ratchet should be rather small and should not move more than two or three teeth per stroke; otherwise, the driving pawl will strike the teeth too hard. Occasionally, a ratchet wheel will jump forward several teeth, owing to lack of resistance; this occurs chiefly when the lubricator has only one or two plungers to operate and can be overcome by tightening the gland packing on the lubricator shaft, where it passes through the container, or by fitting some sort of brake on the shaft.

Lubricators for exposed conditions, *e.g.*, locomotive lubricators, should have the ratchet wheel enclosed in an oiltight casing filled with oil, or the ratchet should be inside the container.

Feed Adjustment.—With ratchet drive an alteration in feed is made by altering the leverage or angular movement of the actuating arm, which means a greater or smaller *number of strokes per minute.* An alteration in the amount of *oil fed per stroke* can be made by having a by-pass on the delivery side, by wiredrawing the oil inlet (suction passage), by altering the stroke of the plunger, by keeping the suction valve or port open for part of the delivery stroke, etc.

The first two methods are very unsatisfactory, particularly with viscous oils, as any alteration in viscosity means an alteration in oil feed. One method of altering the plunger stroke is shown in Fig. 11, *viz.*, by altering the position of the two adjusting nuts; they may be so adjusted that the plunger is never touched by the cam roller—no-stroke position—or they may allow the cam roller to touch the plunger all the time—full-stroke position—any intermediary position can also be secured.

Keeping the suction ports or valves open during part of the delivery stroke has the same effect as shortening the plunger stroke and, with a well-designed arrangement, is capable of giving good results. With the two last-mentioned methods the oil feed, assuming that the valve arrangement is satisfactory, will be maintained uniform and independent of the viscosity of the oil, as long as the speed is low enough and the oil fluid enough at the working temperature entirely to fill the pump space on the suction stroke. With steam-cylinder oils the number of long strokes per minute must not exceed 20 to 30 to get perfect pump action, say above 90 per cent volumetric efficiency; with

medium-viscosity internal-combustion engine oils, a speed of 250 to 300 short strokes per minute may be permitted.

There are multiple-feed lubricators in which one large master pump supplies oil for a number of delivery pumps, the feed to each of them being controlled by a drip-sight feed; the surplus oil delivered by the large pump over and above what is taken by the delivery pumps is by-passed back to the container through a loaded check valve. In this arrangement the oil feeds are much influenced by alteration in viscosity of the oil (temperature changes); also, an alteration in one of the feeds affects the other feeds.

For these reasons the author is a strong advocate of separate, independent, and interchangeable pump units for each oil feed, *e.g.*, the pump unit in Fig. 11, which represents a design by A. Kirkham and the author. But this principle of separate pump units for each feed can, of course, be applied to any number of designs.

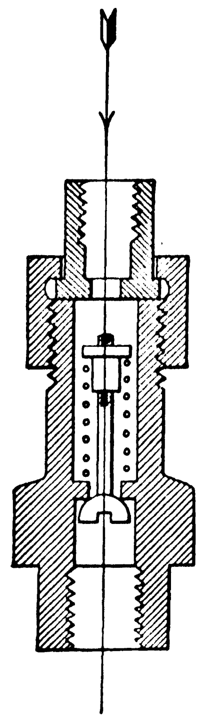


FIG. 15.—Check valve.

Heating Arrangement.—Lubricators that are exposed to low temperatures and have to pump viscous oils, *e.g.*, lubricators on locomotives, steam traction engines, etc., must be fitted with heating tubes. Usually, a straight tube through the container as near the suction ports as possible, or even a short hollow tube screwed into the container, will prove adequate; they must be connected to the steam supply, say 10 min. before starting, so as to liquefy the oil sufficiently to ensure good pump action.

Strainer.—Most lubricators have a shallow perforated strainer through which viscous steam-cylinder oil passes so slowly that the average driver never troubles to use the strainer but takes it out when he fills the lubricator; even if it is not removed, it retains only coarse impurities. It is best made of gauze, which has finer openings than perforated plate and yet a considerably greater area of openings to pass the oil. The strainer should be deep, as shown in Fig. 11, and with a solid bottom and rim, so that any dirt or water in the oil may accumulate here while the oil filters through the sides.

Check Valves.—At the extreme end of the oil pipes should be fitted spring-loaded nonreturn valves to prevent the oil pipes from emptying themselves; the force of the spring should be 20 to 25 lb. per square inch, so as to prevent a vacuum from opening the valve and sucking oil out of the pipe and lubricator; this is not an unusual occurrence with badly made check valves. To ensure good seating of the valve, the author favors ball valves with the spring soldered on to the ball; this prevents the ball from rotating, and it forms a good permanent seating which should preferably be very narrow.

Figure 15 illustrates one type of check valve which the author has used with great success. Figure 155 (page 418) shows a locomotive-pattern check valve.

Desirable Features in Mechanically Operated Lubricators.—In the author's opinion the things to aim at in the manufacture of a first-class mechanically operated lubricator are the following:

1. Oil feeds independent of each other.
2. Oil feeds independent of viscosity, oil level, or back pressure.
3. Sight feeds showing the correct amount of oil actually passing out from the lubricator.
4. Oil feeds capable of quick adjustment between wide limits.
5. Freedom from air lock.
6. All adjustments outside.
7. All parts easily accessible for adjustment, examination, or cleaning.
8. No joints under pressure except final discharge.
9. Low wear of parts.
10. Efficient strainer.
11. All pump units made up of standard, interchangeable parts.
12. Adaptability for ratchet drive, rotary drive, worm-gear drive, spur-gear drive, or oscillating-lever drive.
13. Simplicity and compactness of design.
14. Low cost of manufacture.

CHAPTER VIII

BEARINGS

(Bearings in General)

Bearings are used to support the revolving or oscillating parts of engines and machinery, and the problem of bearing lubrication is therefore the oldest of all lubricating problems.

In the early days, bearings were crudely designed, and low-speed conditions prevailed. The lubricating mediums were vegetable oils, such as olive oil; rapeseed and castor oil; and animal fats and oils, such as tallow, lard oil, sperm oil, and whale oil.

The enormous development of modern engines and machinery has brought into existence a variety of bearings operating under higher speeds, higher pressures, or higher temperatures than at any time before. Lubricating oils to suit modern conditions have of necessity undergone a similar great development, made possible by the production of mineral lubricating oils manufactured from a variety of petroleum crudes. The subject of bearing lubrication will be divided into several sections as follows:

Construction.
Bearing Materials.
Workmanship.
Operating Conditions.
Oiling Systems.
Frictional Heat.
Bearing Troubles.
Lubrication.
Selection of Oil.
Bearing Oils.
Semisolid Lubricants.
Solid Lubricants.

CONSTRUCTION

Bearings are made in all sizes from very small to very large, and there are two main types, as follows:

Journal Bearings

1. Solid bearings.
2. Two-part bearings.
3. Four-part bearings.
4. Ball and roller bearings.
5. Michell and Nomy bearings.

Thrust Bearings

1. Plain thrust bearings.
2. Ball and roller thrust bearings.
3. Michell and Nomy bearings.

Journal Bearings. 1. *Solid Bearings.*—Horizontal solid bearings are always small in size, used as inexpensive bearings for loose pulleys and small shafts and in a variety of machinery where slow speeds or low bearing pressures prevail or where the lubricating conditions are so excellent that little or no wear is anticipated. This type of bearing is used as gudgeon or wrist-pin bearing in the great majority of high-speed steam engines and internal-combustion engines.

When more than slight wear is likely to take place a bushing is frequently provided so that when the bushing is worn it can be replaced.

Vertical solid bearings are used as neck bearings and footstep bearings for high-speed spindles in textile mills, also as footsteps for vertical shafts.

2. *Two-part Bearings.*—The majority of bearings are of this type. For shafting bearings the two bearing halves are usually of cast iron, and the bearing comparatively long. They may be hand oiled, drop-feed oiled, or arranged for ring oiling.

In larger journals, bearing brasses are fixed in the top and bottom part of the bearing, and between the top and bottom brasses are placed "liners," which are thin strips of metal. When the bearing wears, one or more of these strips may be removed, so as to bring the two bearing brasses closer together around the shaft. Two-part bearings are often lined with antifriction metal.

When the pressure is always taken by one of the brasses, say the lower one, as in many bearings, the top half of the bearing need not be very strong, nor does the top brass need to fit the journal closely; in many cases the top half then simply acts as a dust cover and to hold the lubricator. Railway axle boxes, for example, have only a top brass, the pressure being directed upward, and below the journal is a cellar, holding a pad oiler or waste packing for the purpose of lubricating the journal.

A two-part bearing is not suitable where the pressure from the journal is directed against the joint of the two bearing halves;

large bearings operating under such conditions are therefore frequently designed as four-part bearings.

3. *Four-part Bearings.*—These bearings are used principally as main bearings in large horizontal steam engines and gas engines. The bearing surface is built up of four parts, *i.e.*, a top and bottom brass and two side brasses.

4. *Ball and roller bearings* are described in a special chapter.

5. Michell and Nomy bearings are described in a special chapter.

Thrust bearings are designed to take up pressure in the direction of the shaft, *e.g.*, the propeller thrust in the case of marine steam engines and turbines. A special chapter is devoted to the description of plain thrust bearings, ball and roller thrust bearings are described under ball and roller bearings, and Michell and Nomy thrust bearings are described in the special chapter devoted to these bearings.

BEARING MATERIALS

With perfect oil-film lubrication the nature of the rubbing surfaces does not influence lubrication, but most bearings are imperfectly lubricated; they wear more or less, and the various bearing metals behave differently.

Bearings are chiefly metals, but wood, rawhide, fiber, agate, and jewels are used for special purposes.

Bearing Metals.—The journal and the bearing should preferably be of dissimilar materials to work well together, and the bearing surface is usually of a softer material than the journal. If wear takes place, it will then be chiefly on the bearing surface, which is cheaper to replace than the journal.

Good bearing metals must possess the following properties:

1. *Sufficient strength to sustain the load.*

2. *Low running temperature,* which means high thermal conductivity; white metals containing a high percentage of lead are inferior in this respect to those rich in tin and containing little or no lead.

3. *Low Coefficient of Friction.*—Hard bearing materials, such as the rigid bronzes (copper-tin alloys low in lead), are best in this respect, assuming that the bearing surfaces are carefully fitted to the journal; otherwise, white metals give lower friction, as they yield slightly and distribute the load more uniformly.

4. *Durability.*—The rigid bronzes, and alloys containing zinc, wear more than those alloys which are rich in lead, but the latter have a higher coeffi-

cient of friction. According to Dudley, those bearing metals will wear the least which have a fine granular structure and combine great elongation with great tensile strength, the elongation, however, being the more important property of these two.

5. *Low Journal Wear.*—The white metals excel over other metals.

6. *Ease of Replacement.*—Again here the advantage lies with the white metals.

7. *Resistance to Corrosion.*—Tin and antimony resist corrosion best; iron, copper, lead, and zinc are more easily corroded, particularly the two latter. When the oil is likely to contain a large amount of free fatty acid, the white metal should preferably contain no lead and little or no zinc.

The following combinations of bearing metals represent current practice:

Hardened Crucible Steel on Steel or Bronze.—For high pressure and low or moderate speed, *e.g.*, hard-steel toggles working against mild-steel seats in stone breakers, presses, etc.

Mild Steel on Bronze.—For moderate pressures and low or moderate speeds, as exist in many important bearings.

Mild Steel on White Metal.—For low or moderate pressures and moderate or high speeds. This is the combination used in the great majority of machinery bearings.

Mild Steel on Cast Iron.—For low or moderate pressures and low speeds, as in textile machinery and the like; also used for small or medium-size shafting bearings; the bearings are long, and the pressures low; with higher bearing pressures, the cast iron must be lined with white metal.

Cast Iron on Cast Iron.—For low pressure, chiefly used for piston rings, cylinders, crossheads, and crosshead guides in steam engines and internal-combustion engines.

Hard Steel, Bronze, or Brass.—With all hard bearing metals it is important that the bearing surfaces be well scraped together with the journal and that the bearings be carefully erected, so that the pressures will be evenly distributed over the entire bearing surfaces; otherwise, certain parts of the bearings will be excessively loaded and cause heating.

White metals (antifriction metals) are combinations of hard metal, such as antimony, embedded in a soft plastic groundmass, such as lead.

When lined with suitable antifriction metal, which has more or less resilience, the journal easily beds itself down and distributes the pressure uniformly over the entire bearing surface.

In high-speed steam and internal-combustion engines, where three, four, or five bearings support the crankshaft, the bearings are nearly always lined with white metal, with a view to distributing the load equally over them all.

If bronze is used and if, say, one bearing is slightly out of line, the bronze, not yielding, will create excessive bearing pressure in that particular bearing and cause heating.

It is the hard grains in a white-metal surface that sustain the load; if the load is excessive at any point, the plastic body of the metal will yield until the load is evenly distributed over a great many hard grains; this will assist the lubricating oil in maintaining a good film everywhere and means increased safety in operation. If there are only a few hard grains in a white metal, it will be soft and will stand only low bearing pressures; if there are too many hard grains, the points of the hard crystals will engage one another and form a solid network throughout the body of the metal, which will then be found to be brittle. Trimetal alloys appear to give better service than those white metals which are composed of only two metals.

Cast iron is porous and granular in structure; close-grained cast iron is best and can be obtained harder or softer as required. It is capable of attaining a very smooth, hard, and glazed surface; but if this surface is cut it takes considerable time to reproduce the hard glossy skin so very desirable from a lubrication point of view.

Cast iron when not exposed to undue pressure and when well lubricated is a very satisfactory bearing metal.

The use of graphite in connection with cast iron is capable of giving excellent results, as mentioned under "Solid Lubricants."

Wood, Rawhide, and Fiber.—Hard and dense wood is used to some extent for spur and bevel gearing in windmills, water mills, etc. For certain bearings, such as footsteps for water turbines and stern tube bearings, lignum vitæ is favored, as it will stand great pressure, is of a greasy nature, is not easily abraded, and works well with water.

Rawhide and fiber, also compressed paper, are sometimes used for pinion wheels and give silent running.

Agate and Jewels.—In watches and light machinery, which cannot be regularly lubricated, agate and various jewels are used as bearings for hard-steel pins.

WORKMANSHIP

Workmanship may be defined as the attention that has been given to

1. The finish of the bearing surfaces.
2. The bearing clearance.
3. The alignment of the erected bearing.

Finish of Bearing Surfaces.—The rubbing surfaces are never exactly true and smooth. If a new shaft is put into new bearings without oil, it will, when revolving, touch the bearing surfaces only at certain points, distributed more or less evenly over the surface. It is for this reason that bearings are "scraped together." It is an advantage to have the surface of the shaft made as smooth as possible, and the high points in the bearing surfaces are scraped down until finally the shaft bears uniformly on the whole of the bearing area.

Bearing Clearance.—The diameter of the shaft is slightly smaller than the inside diameter of the bearing. The difference between the two diameters—the bearing clearance—should be about 1/1,000 in. per inch diameter of the shaft—rather more than this for small bearings and rather less for large bearings.

When the bearing surfaces are well lubricated, and particularly when they are supplied with a continuous stream of oil, which carries away the frictional heat, the bearing clearances can be made smaller, and more efficient lubrication can be obtained than where bearings are boundary lubricated and the journals therefore are more likely to heat and expand.

Alignment.—When machinery and shafting are erected, it is very important that the various bearings be truly and accurately fitted. If, for instance, a length of shafting is supported by a number of bearings, and some bearings are placed too high and others too low, this will set up stresses in the shafts and in the bearings, creating difficult lubricating conditions.

OPERATING CONDITIONS

Size of bearing (diameter).
Speed of shaft (surface speed per minute).
Bearing pressure (pounds per square inch).
Bearing temperature (degrees Fahrenheit).
Mechanical conditions (good or bad).

Size of Bearing.—The surface of the shaft or journal is never perfectly smooth or round but will possess a roughness which, if not visible to the naked eye, can be seen through a magnifying glass. The imperfection in manufacture will have a tendency to produce metallic contact between the rubbing surfaces. This

tendency is greater the larger the bearing, and experience has proved that, other things being equal, the larger the bearing the heavier in body must be the oil to provide efficient lubrication.

Speed of Shaft.—A revolving shaft will draw the oil into the bearing owing to the oils adhering and clinging to the shaft. Speaking generally, this action increases with the speed of the shaft and the body of the oil. When bearings operate at low speed, the oil used *must* be heavy in body, and grease may be preferable in some cases. At higher speeds, an oil light in body should preferably be used; and for very high speeds, oils very light in body *must* be used.

Sommerfeld gives the following formula for the minimum speed at which the friction in the bearing changes over from "boundary friction" to fluid friction:

$$V_{\text{min.}} = \frac{1}{15.1} \cdot \frac{P}{\eta} \left(\frac{\delta}{r}\right)^2$$

where V is expressed in meters per second.
P is bearing pressure in kilograms per square centimeter.
δ is bearing clearance in centimeters.
r is radius of shaft in centimeters.
η is absolute viscosity in poises.

At extremely high speeds, *air* even has been used as the only lubricant, as in the case of spindle bearings for traverse spindle grinders used in watch factories. The spindles are ½ in. in diameter. Both spindles and bearings are of hardened steel and fitted together with extreme care; the fit is so close that when they are not running it is difficult to slide the spindle through the bearing.

When starting up, the spindles will give a grating noise for a few seconds; but when attaining their normal speed of about 12,000 r.p.m., they run quite smoothly and with so little friction that, when the driving belt is thrown off, they continue to run for a couple of minutes until the air film breaks and the spindles quickly stop. The surfaces must be kept very clean by rubbing with alcohol and tissue paper. If the bearings or spindles are not perfect, a little kerosene needs to be used to give smooth running.

Bearing Pressure.—Bearing pressures range from a few pounds per square inch for cast-iron piston rings rubbing against cast-

iron cylinders to as much as 3,000 to 4,000 lb. per square inch for hardened steel rubbing against steel, as in slow-speed punching machines. The bearing pressures are chiefly governed by the nature of the bearing materials, the character of the load, and the degree of lubrication efficiency desired.

For ordinary conditions the bearing pressures permissible for various metals are indicated in the following table:

	Pressures, Pounds per Square Inch
Hardened crucible steel on steel	2,000
Hardened crucible steel on bronze	1,200
Unhardened crucible steel on bronze	800
Mild steel with smooth compact surface on bronze	500
Mild steel with ordinary surface on bronze	400
Mild steel with ordinary surface on white metal	500
Mild steel on cast iron	300
Cast iron on cast iron (journal bearings)	100

These figures may be increased 50 per cent, 100 per cent, or even more, if the load is intermittent, also if the bearings are well cooled, as in locomotive crankpins and crossheads.

The figures must be reduced if the pressure is always in one direction and never relieved; also, if it is important that no wear should occur, as in many electrical machines and other high-speed engines, such as enclosed-type steam engines and gas engines, lubricated by a circulation oiling system. If wear must not take place, it means that the bearings must have perfect oil-film lubrication at all times; with high surface speed, higher bearing pressures may be allowed, as the oil film is more easily formed. But the accuracy and smoothness of the working surfaces is also exceedingly important, to enable an unbroken oil film to form. This intricate subject has been treated mathematically in a very thorough and practical manner by E. Falz, in his book "Grundzüge der Schmiertechnik."[1]

All other things being equal, it is obvious that the greater the pressure on the bearing and the lower the speed the heavier in body must the oil be to sustain the pressure without being squeezed out too rapidly. If the pressure on the bearing is slight, light-bodied oil can be used, and at moderate or high speeds a moderate oil supply will be sufficient to maintain a complete

[1] Julius Springer, Berlin.

oil film. If the pressure on the bearing is great, an oil heavy in body must be used; and if, in addition, the speed is low, it is very difficult, if not impossible, to maintain a complete oil film and to prevent metallic contact of the rubbing surfaces. Under such conditions certain solid or semisolid lubricants may prove more efficient than lubricating oils.

Bearing Temperature.—Where machinery is operating in cold surroundings, or at very low speeds, bearing temperatures may be *low* (from 70 to 90°F.). When bearings operate in very cold surroundings, light-bodied oils and oils with low cold tests should be employed, so as not to congeal and cause difficulty in feeding.

The majority of bearings operate at *medium* temperatures, from 90 to 120°F. High-speed bearings frequently operate at temperatures higher than 120 but seldom above 160°F. Bearing temperatures above 120°F. must be termed high and should ordinarily never be allowed to exceed 140°F. (see "Turbines").

If the bearing temperature is higher than 160°F., the conditions should be carefully looked into, as such temperatures are dangerous and show that the mechanical conditions are wrong and should be corrected or that the quality of the oil used is unsuitable or that an insufficient quantity of oil reaches the parts to be lubricated.

If bearing temperatures are high, notwithstanding that the mechanical conditions are correct and that carefully selected good-quality oil is used in sufficient quantity, the conditions are evidently so severe that the heat developed in the bearing cannot be radiated quickly enough from the bearing surface. In such cases a circulation oiling system should be introduced, in order to remove the frictional heat and reduce the bearing temperature sufficiently for safe operation.

Mechanical Conditions.—Bearings, in time, will usually wear or get out of alignment; it is important that they be kept in good alignment and repair, by renewing bushings, brasses, or anti-friction linings; by adjusting bearings for wear; etc.

When trouble or irregularity in operation occurs, the cause should be traced, and the conditions rectified, rather than that the trouble should be allowed to continue until it becomes serious.

By *good mechanical conditions* is understood bearings of good design; journals and bearing surfaces of good material, well finished and with suitable bearing clearance; bearings in good

alignment and not appreciably worn; also reasonable attention to regular oiling of the bearings.

By *bad mechanical conditions* is understood bearings that are crudely designed, or of good design but allowed to get out of order; bearings made of poor or unsuitable material; bearing surfaces rough or worn, bearings out of alignment; also lack of attention in keeping the oiling system in its most efficient state.

Speaking generally, bad mechanical conditions necessitate the use of oils heavy in body, whereas under good mechanical conditions oils lighter in body can be employed, resulting in more efficient lubrication of the bearings.

OILING SYSTEMS

The various systems by which oil is applied to bearings may be divided into seven main groups, as follows:

Individual bearings	Hand oiling. Drop-feed oiling. Pad oiling. Ring oiling. Bath oiling.
Groups of bearings	Splash oiling. Circulation oiling.

Oiling Systems for Individual Bearings.—Hand oiling is the oldest system employed for lubricating bearings; it is the least efficient and the most wasteful of all oiling systems. Hand oiling is employed for lubrication of low-speed shafting and low-speed bearings in a variety of machines, such as machine tools, textile machinery, and printing machines. It is largely employed for oiling small parts of valve motions, valve spindles, etc., in steam engines, internal-combustion engines, and other power producers. It is also employed on various types of machines exposed to heavy vibration or rough use where any kind of lubricating appliance would be shaken off.

In the bearing is a hole, usually in the top part. The oil is applied by an oilcan, preferably of the press-button type, by which it is possible to deliver one drop or a few drops of oil as required, in order not to waste it. The oil runs down the hole, spreads over the bearing surfaces, and gradually works its way toward and out through the ends of the bearing. After each oiling, the oil film in the bearing gradually becomes thinner, and

finally the bearing runs practically without lubrication until such time as it is oiled afresh.

The lubrication will gradually decrease to a state of inefficiency, dependent upon the body of the oil in use, the length of time between oilings, and the operating conditions.

In order to prevent the entrance of dust or fluffy matter, which would tend to choke up the oil hole or would enter the bearing and cause trouble, the entrance to the oil hole may be fitted with an oil-hole protector (see Figs. 109, 110, 111, page 302). Another method is to provide a felt pad in the oil hole into which the oil is poured. This method insures more uniform feeding of the oil.

In many cases the oil is not applied through an oil hole but simply to the end of the bearing, *e.g.*, with textile machinery.

Drop-feed Oiling.—The drop-feed oiling system includes all appliances by which a moderate and more or less regular supply of oil is fed to the bearing.

There are four types of such appliances, *viz.:*

Siphon oiler.	Sight-feed drop oiler.
Bottle oiler.	Mechanically operated lubricator.

Siphon Oiler.—When, in the early days of engineering, hand oiling proved inadequate for lubricating heavy-duty bearings, the siphon oiler was the first improvement introduced. It (Fig. 16) consists of a container (1) in which oil is filled to a certain level; the siphon oil tube (2) projects above the oil level; the siphon wick is introduced into the oil tube, its lower end being at a lower level than the end immersed in the oil. The oil level should not be allowed to be higher than the top of the oil tube, as the surplus oil will then be wasted through the tube.

With siphon oilers the oil feed varies with the oil level in the container, also with the temperature of the oil, as cold and thick oil will feed more slowly than warm and thin oil.

The siphon wick consists usually of one or several strands of woolen yarn, preferably of loose texture, which feed more freely than yarns of tight twist and close texture. The higher the oil level in the container, or the thinner the oil, or the deeper the siphon is introduced into the oil tube, or the greater the number of strands in the siphon the greater will be the oil feed. When so many strands are used that they choke the oil tube, a point is reached where the addition of more strands will reduce the oil

feed because of the greater resistance in passing through the tight siphon; choke trimmings used in locomotives (Fig. 98, page 284) are of this type.

The container should always be fitted with a lid, so as to prevent the entrance of dust, dirt, and water into the oil. Siphons in time get choked with impurities and become inoperative; they should be renewed at suitable intervals.

Siphon oilers are rather wasteful but very reliable where a moderate oil feed is required; they are not suitable for very small feeds. Where machines or engines are running intermittently, the siphons should be lifted out of the oil tube and left in the oil

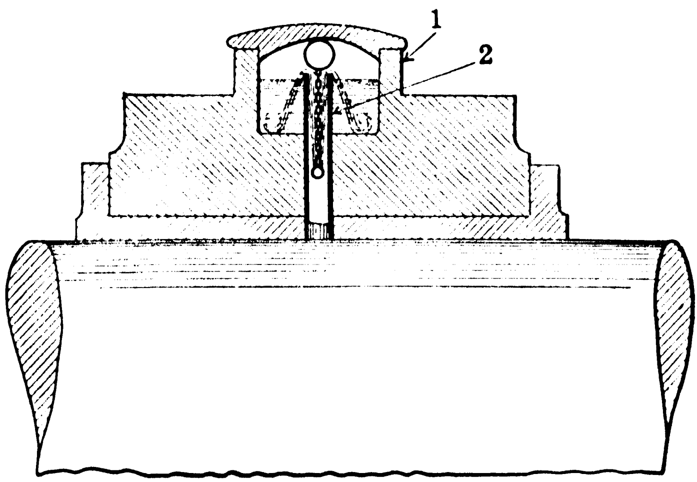


FIG. 16.—Siphon oiler.

container every time that the machinery stops; otherwise, they keep on feeding, and oil is wasted; oil should be added to the container at frequent intervals so as to keep the oil level as constant as possible.

Siphon oilers are employed for lubrication of locomotives, marine steam engines, main bearings of old-type stationary steam engines, and other prime movers, as well as for the lubrication of medium-size bearings of shafting and in a variety of machines of all kinds.

The oil container may have several siphon tubes, each tube being served by a separate siphon; such multiple-feed siphon boxes are occasionally fitted with sight-feed glasses below the container, so that the oil feed from each siphon tube is visible.

The bottle oiler (Fig. 17) has been specially developed for the lubrication of light and medium-sized shafting bearings operating at low to moderately high speed and under conditions that make a small constant feed desirable. The glass bottle (1) has a stopper (2) fitted with a brass tube (4). A copper or steel needle (3) fits loosely inside the brass tube, its lower end resting on the shaft in the bearing.

The shaft, when revolving, gives the needle a very slight up-and-down motion, which has the effect of drawing a sparing supply of oil from the glass bottle, the oil creeping down over the surface of the needle and finally reaching the bearing surface.

The bottle oiler is automatic in action, starting and stopping with the motion of the shaft. If the bearing gets warm, the needle heats up; the oil surrounding the needle becomes thinner, and more oil will be fed. If the bearing vibrates, the greater movements of the needle will result in more oil's being fed. If it be found that the amount of oil supplied through the bottle oiler is insufficient, the oil feed can be increased by using a thinner needle or by filing a flat on the side of the needle.

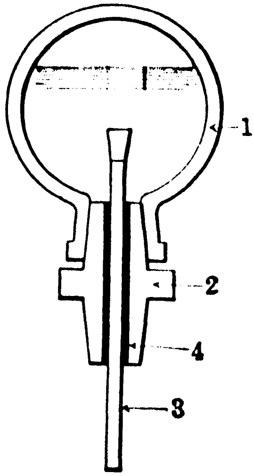


Fig. 17.—Glass bottle oiler.

The stopper should preferably have a brass tube, as shown, in which the needle has a loose sliding fit; without this tube the opening in the stopper varies considerably and in time causes the oil feed to stop on account of the swelling of the stopper.

Bottle oilers cannot be used on machinery exposed to rough use, as, being of glass, they are easily broken.

The sight-feed drop oiler (Fig. 18) has largely replaced the siphon oiler. It can be adjusted to feed one drop of oil per minute or more. It consists of a container, usually having a glass body so that the level of the oil can be observed. The adjusting needle or valve spindle (5) is guided into a conical hole in the bottom of the oiler. By turning the milled collar (3) the needle can be raised or lowered so as to give a greater or smaller feed. If the handle (4) of the top of the adjusting needle 5 is turned to its horizontal position, the needle drops by spring tension and shuts off the oil supply; when it is again raised, the feed will be the same as previously adjusted.

The sight-feed drop oiler has the same disadvantage as the siphon oiler as regards variation in oil feed, due to higher or lower oil level or due to the oil being cold and thick or warm and thin; in addition, when adjusted to feed a very small amount of oil, grit and dirt may easily choke the oil outlet from the oiler, so that the feed stops altogether. The sight-feed drop oiler has the advantage over the siphon oiler in that the feed can be quickly adjusted, quickly started and stopped, and the oil level as well as the oil feed is clearly visible.

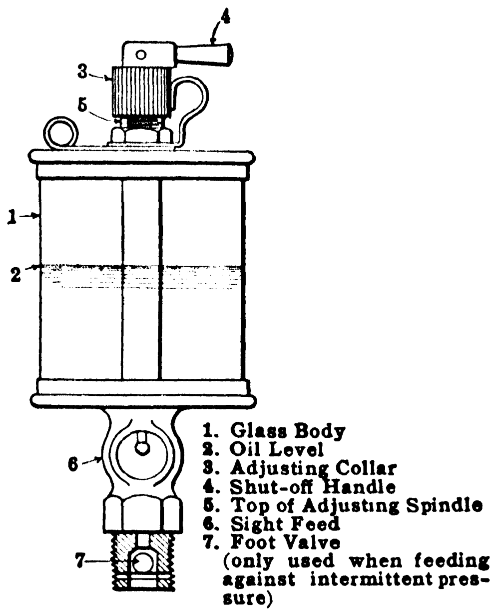


Fig. 18.—Sight-feed drop oiler.

Sight-feed drop oilers may be arranged to have more than one feed. For example an oil container may have six oil outlets, controlled by six different needle valves, the oil dropping through sight feeds into oil tubes which guide the oil to the different bearings.

Sight-feed drop oilers are extensively used on modern steam engines and power producers of all kinds.

When feeding oil to the crankpins of steam engines, gas engines, and other prime movers, the so-called crankpin banjo oiler is often employed (see Fig. 171, page 465).

The Nugent crankpin oiler, much used in the United States, is shown in Fig. 19. The sight-feed drop oiler is held in a vertical position by the weighted pendulum (1) to which it is attached.

The part (2) revolves centrally, receives the oil through the tube (3), and guides it to the crankpin.

A mechanically operated lubricator, either single feed or multiple feed, is occasionally employed for feeding oil to important bearings. The advantage is that, being operated from a moving part of the engine, the mechanically operated lubricator starts and stops with the engine and feeds the oil more uniformly and regularly, therefore with less waste, than when sight-feed drop oilers or siphon oilers are used; also a much more viscous oil can be fed, if required. The various feed pipes are preferably fitted with check valves at their extreme ends in order to ensure that the pipes are always filled with oil, so that as soon as the engine starts, and therefore the lubricator, the oil will immediately be delivered from the ends of the oil pipes.

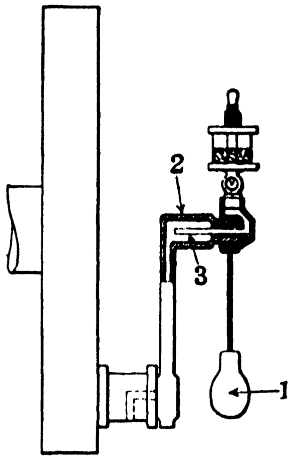


FIG. 19.—Nugent crankpin oiler.

Sight-feed arrangements are either fitted in the lubricator itself, one sight feed for each oil feed, or fitted at the extreme ends of the oil pipes, the oil dropping from the check valves through sight feeds into the bearings.

Pad Oiling.—Lubrication by pad oilers or oil-soaked waste is used chiefly in railway practice and described under "Railway Rolling Stock."

Ring Oiling.—This method is very efficient and is described in a special chapter.

Bath Oiling.—This system is employed only for vertical bearings, such as ball bearings; high-speed bath spindles employed in textile mills; or the footsteps of vertical, heavy shafts, sometimes found in textile mills, flour mills, vertical water turbines, vertical hydroextractors, gyratory crushers, etc. (see under respective headings).

Oiling Systems for Groups of Bearings.—*Splash oiling* is employed for lubricating a number of bearings enclosed in an oiltight casing, this system being frequently employed for lubricating enclosed vertical or horizontal steam engines, air compressors, gas engines, kerosene engines, gasoline engines, and motorcycles.

The enclosed crank chamber is filled with oil to a certain level; means should be provided to maintain this level as constant as possible. Dippers fixed to the crankpin bearings (big ends) dip into the oil and produce inside the crank chamber a spray of tiny drops of oil which reach and lubricate the main bearings, crankpins, gudgeon or wrist pins, cams, and various other bearings or parts. The bearings have oil holes or oil troughs which catch the oil from the spray and guide it into the bearing surfaces.

In some small steam engines, in motorcycle engines, and in certain types of automobile engines, the crank disk or the flywheel revolving inside the crank chamber may be arranged so that it dips into the oil, and as the oil adheres to the revolving rim an oil spray will be produced. Oil wells or pockets may be cast on the inside of the casing, collecting the oil and assisting it through various channels, tubes, or troughs, in reaching all parts.

If the *oil level is too low*, too little oil spray will be formed; some of the parts will be starved, resulting in inefficient lubrication. If the *oil level is too high*, too much oil spray will be formed, which always results in waste of oil, the oil spray escaping from the bearings or from the air vent usually provided in the crank chamber.

Excessive oil spray in the case of automobile engines, motorcycles, and other internal-combustion engines is detrimental, producing excessive carbonization on the hot pistons. In the case of vertical steam engines, excessive oil spray means that too much oil passes the pistons and finds its way through the engine with the exhaust steam; this means always waste and sometimes trouble where it is important that the exhaust steam should be as free from oil as possible.

Circulation Oiling.—There are two main systems embodying the circulation principle, *viz.:*

Gravity-feed circulation.
Force-feed circulation.

The *gravity-feed circulation system* is a central automatic oiling system for lubricating a number of bearings and parts, *e.g.*, the main bearings, crankpins, crossheads, crosshead guides, etc., comprising most of the external moving parts in medium- or large-size open-type steam engines, gas engines, Diesel engines, steam turbines, groups of large shafting bearings, etc.

Oil is fed by gravity from a top supply tank through a distributing pipe and its branch pipes leading to the various bearings. Adjusting cocks are fitted in these branch pipes so as to regulate the oil feeds, and sight feeds are frequently fitted in the oil inlet or outlet pipes to the bearings so that the oil feeds are clearly visible. Sometimes, as in the case of steam turbines, the sight feeds are fitted in the outlets from the bearings, showing the amount of oil that *has passed* through the bearings. Having done its work, the oil drains back from the various parts through return oil pipes to a bottom receiving tank. The oil pump driven by the engine takes the oil from the receiving tank and delivers it either through an oil cooler or direct into the top supply tank. If more oil is delivered to the top tank than is required for the bearings, the surplus oil passes through an overflow back into the bottom receiving tank.

Drainpipes are fitted to the top tank and bottom tank to enable the operator to drain out water, sludge, or impurities when required; also the whole or part of the contents of the tanks may be withdrawn for treatment in a separation and filtration plant.

It is always difficult to avoid some loss of oil. Oil is lost in the form of oil spray, particularly when the speeds are high, and is wasted through tiny leaks difficult to avoid and often difficult to locate. The loss of oil can be reduced somewhat by reducing the amount of oil fed to each bearing, but this is doubtful economy, if the lubrication becomes less efficient; sufficient oil should be fed so that a good oil film will be maintained, and friction and wear reduced to the minimum.

A heavy-viscosity oil will cause less loss by leakage or oil spray than a low-viscosity oil; but here, again, the bearing friction is usually increased, so that from an oil-loss point of view very viscous oils should be introduced only if the leakage losses are quite abnormal. It pays to provide good save-alls and splash guards, not only to save oil but also to save the foundations. Oil-soaked parts of a foundation are weak and crumbly and a constant source of danger to the engine.

The *force-feed circulation system* operates on lines exactly similar to the gravity-feed circulation system, the difference being that the top tank is omitted and the oil passes direct into the distributing pipe, which should preferably be fitted with an

adjustable relief valve, a portion of the oil being by-passed back into the bottom tank. The oil is thus delivered under pressure as direct as possible to the various bearings and parts requiring lubrication.

This system is largely employed for lubricating all sizes of enclosed-type steam engines, Diesel engines, vertical kerosene engines, gasoline engines, steam turbines, etc.

Daily Treatment.—In the cases of both splash oiling and oil circulation it is good practice to remove 2 to 6 gal. of oil every day for treatment in a heated separating tank to separate out water, sludge, and impurities and afterward to pass the oil through a good filter; the purified oil, mixed with a little fresh oil, should be returned to the system at the same time that a corresponding quantity of oil is removed from the system for treatment. When the oil-tank capacity in the system is small, it is particularly desirable to recommend this practice. In this way the vitality of the oil is kept up to as high a standard as possible, and the life of the oil is greatly increased.

In very large plants, the separation and the filtration apparatus are preferably constructed as a part of the circulation system, so that either the whole of the oil in circulation or a certain percentage of it is constantly passed through the purifying apparatus.

Care of Oiling Systems.—Whatever oiling systems may be employed, it is important that the necessary attention be given to institute a regular routine for maintaining the oiling systems at their highest efficiency.

Bearings that are hand oiled should be oiled at sufficiently frequent intervals to ensure the presence of an oil film and prevent excessive heating. The oil containers in siphon oilers, bottle oilers, sight-feed drop oilers, and mechanically operated lubricators should be filled at correct intervals, and a regular system should be employed for putting the oilers into and out of service as may be required. Lubricators never should be allowed to run empty or to become choked with dirt, and they should be cleaned occasionally.

OIL DISTRIBUTION

Reaching the bearing, the oil is conducted to the bearing surfaces through drilled holes; in order to prevent oil from being wasted between the bearing cap and brass, a tube should be

tightly fitted at this point. The edges of the brasses at the side where the oil enters should be chamfered, so as to facilitate the entrance of the oil to the bearing surface. This is of paramount importance.

In bearings employing the ring-, splash-, and circulation-oiling systems, where the bearings are copiously supplied with oil, oil grooves are nearly always detrimental; there is usually only an oil-distributing groove, which runs nearly the whole length of the bearing. This oil-distributing groove should be on the side of the bearing where the direction of the revolution of the shaft is downward, and its lower edge should be chamfered so as to facilitate the entrance of the oil.

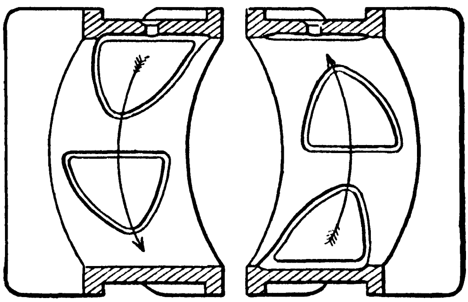


FIG. 20.—Oil grooving a large crankpin bearing.

In bearings that are hand oiled or lubricated by a drop-feed system, in which only a moderate supply of oil is introduced into the bearings, and where a perfect oil film does not exist, it sometimes becomes desirable not only to have an oil-distributing groove but also to have other suitably cut oil grooves to distribute the oil to the bearing surface.

Under the influence of the bearing pressure the oil is squeezed toward the edges of the brass; if the surface speed is high, only a small portion will escape, and the loss is replaced at the point where the oil enters the bearing. If the surface speed is low, the oil received by a certain part of the journal gets time to escape and leave the journal surface unlubricated long before that particular point has completed a revolution and can receive more oil. It is under these conditions that a very viscous oil of good body should be used and that oil grooving is desirable. The oil grooves should be so cut as to feed oil to several points in the bearing and so renew the oil film at these points. Oil grooving is frequently much overdone. Cutting large oil grooves removes the bearing surface which supports the shaft; it is only in large, slow-speed, heavy-duty bearings that oil grooving may become desirable.

Figure 20 illustrates oil grooving in a large crankpin bearing. The oil is introduced at the top, and the action of the oil grooves

is partly to distribute the oil and partly to guide it back toward the middle of the bearing, in order to prevent it from escaping too freely over the ends of the bearing.

Oil grooves should always be cut shallow and have rounded edges; they should not come too close to the end of the bearing brasses; if they are cut close to the ends, oil runs away too freely, is wasted, and the bearing will be inclined to heat.

FRICTIONAL HEAT

The frictional heat developed in a bearing spreads into the journal and into the bearing itself. Where bearings are not water cooled or lubricated by a circulation oiling system, the whole of the heat developed must leave the bearing or journal by radiation into the atmosphere. Bearings, therefore, assume a temperature higher than the surrounding room temperature, and the higher the friction the greater will be the difference between the temperature of any part of the bearing and the room temperature. The difference is termed the *frictional rise in temperature*, or simply the *frictional temperature*, and forms a true guide as to the quality of the oil in service. Any reduction in the frictional temperature brought about by introducing another lubricant will mean that this lubricant is better in quality or more suitable for the conditions.

The frictional temperature remains practically constant for all room temperatures; *i.e.*, if the bearing temperature is 86°F. and the room temperature is 70°F., the frictional temperature is 16°F. If the room temperature rises to 74°F., it will be found that the bearing temperature will rise to 90°F; the friction developed is practically the same, and the bearing temperature must therefore be correspondingly higher, in order to radiate the same amount of heat into the atmosphere.

When bearings operate under conditions of high speed or pressure the heat developed may become so great that it cannot be radiated from the bearing surfaces sufficiently rapidly. Under such conditions it becomes desirable or necessary to introduce a circulation oiling system by which the flow of oil going through the bearings not only serves to lubricate but also removes a large portion of the heat developed, so that this heat, carried away with the oil, can be radiated into the atmosphere from the

oil tanks, oil pipes, etc., or, if necessary, can be removed by an oil-cooling arrangement, as in steam turbines.

Where trouble occurs, it is usually indicated by a tendency of the bearings affected to heat up. It will be instructive to analyze a number of the causes leading to heated bearings.

When the barrels of oil have been delivered, it is important that they be *stored under cover;* they should not be left in the open, exposed to sun and rain, as, particularly if the barrels are stood on end, rain water will find its way through the staves, resulting in the glue coating on the inside of the barrel's being dissolved and spread throughout the oil. When such oil is used, the presence of lining material will cause excessive heating in the bearings.

When *opening a barrel*, the bung should be loosened by striking the staves with a mallet; if an auger is used, fine chips of wood, and dirt from the outside of the barrel, may easily find their way through the opening into the oil. The oil should therefore always be *poured through a strainer* into the oilcans. If this is not done, the small chips of wood and other impurities may get into the bearings and cause trouble.

When the oil is given out from the barrels direct, the overflow oil runs on to the floor or into save-alls, which are not always clean, and there is the danger that some of this oil, including the dirt present, will be given out for lubrication.

It is good practice to *keep the oils in cabinets*, preferably padlocked, so that they are not interfered with by unauthorized persons; there is then no waste.

Dirty oilcans are responsible for many hot bearings, and cans should therefore be kept scrupulously clean; they should be closed at the top or provided with covers, so as to prevent, as far as possible, the entrance of dirt.

An oilcan should never be used for more than one class of oil, and in order to prevent mistakes the name of the oil should be marked on the can.

Numerous hot bearings have been caused by the use of *wrong oil.* If, say, a spindle oil is used instead of an engine oil, it will cause heating, because it is too light in body to provide lubrication. If a very heavy oil is used in place of spindle oil, it will cause heating, and the fluid friction will be excessive,

because it is too heavy to spread over the bearing surfaces, owing to the high speed at which the spindles operate.

In some cases, oils like *linseed oil* or *turpentine* have been used by mistake; in other cases, the use of *badly filtered oil* or *waste oil,* instead of fresh oil, has caused great trouble.

When hand oiling is employed, bearings will be inclined to heat if the *oilings are not sufficiently frequent.*

When drop-feed oiling is employed, many hot bearings are caused by the *lubricators running empty,* particularly when the oil containers are of small capacity. Sometimes bearings heat because the *oil congeals* in the lubricator or in the feed pipes and does not reach the bearings.

Sometimes parts of the lubricator or the oil-feed pipes from the lubricator to the bearings become *choked up with deposits* of various kinds, which may cause a reduction in the oil feed, reducing it to such an extent that the bearing heats.

Fine sawdust in sawmills or woodworking shops, flour dust in flour mills, lint in cotton mills, etc., have been responsible for such trouble. In one case the sight-feed drop oilers were invaded by thousands of tiny little flies, which, after a while, completely *choked the feed pipes* from the lubricators to the bearings.

Cotton waste, still largely used for cleaning down engines and machinery, should not be used for this purpose, as fine fluffy matter from the waste gets into the lubricators and oil, causing trouble. *Mutton or silk cloths* are much to be preferred, as they are free from fluffy matter and can be readily cleaned.

Oil may escape between the bearing keep and the bearing brass, instead of entering the bearing. With a liberal oil feed, the bearing will give no trouble; but when even a small reduction in the oil feed is attempted, the bearing will heat, as it is only the surplus oil that reaches the bearing itself.

Very long bearings sometimes give trouble if they have *too few entrances* for the oil. For instance, a bearing more than 10 in. long and having only one oil inlet by the drop-feed method, in the center, will always be inclined to give trouble.

Some bearings are difficult to lubricate because the *pressure is upward,* instead of downward, which makes it difficult for the oil to spread, unless it is introduced at the bottom of the bearing.

In the case of *ring-oiling bearings,* water of condensation from a very moist atmosphere may enter and accumulate in the bottom

of the bearing and will lift the oil out of the bearing, until finally the *oil rings revolve in water*, and heating occurs. In ring-oiling bearings, deposits formed by the oil itself or by impurities entering the bearing may cause the *oil rings to stick*, so that the oil supply fails and the bearing heats.

Bearings lubricated by the *splash oiling system* may heat, owing to the oil level's being too low to provide adequate oil spray or owing to *emulsification of the oil* by the presence of water of condensation and cylinder oil coming from leaking glands.

Water, from the engine itself, *e.g.*, condensed steam from leaking piston-rod glands, or leaking cooling water, etc., may find its way into the bearings and displace the oil; the bearings start heating as soon as the oil film is destroyed by the water.

Where the entrance of water cannot very well be avoided, the system of *daily treatment* of the oil (see under "Turbines") will always bring about an improvement.

In *circulation oiling systems* bearings may heat because of *deposit choking the oil-inlet pipes.*

Deposits may be due to unsuitable or improperly manufactured oil or to the *mixing of water and oil or of two different oils.* If, for example, an oil heavily compounded with blown vegetable oils gets into the mineral oil in circulation, a large portion of the compound will separate out in the form of a sludge.

If mineral oil has been a long time in circulation and has become very dark in color and considerably weakened, the addition of a large quantity of fresh oil will throw down a dark-colored deposit.

Oil-distributing grooves or oil grooves in the bearings may be choked up for various reasons already given and thus cause trouble, in preventing the proper distribution of the oil.

Speeding up of the machinery, in order to increase production, may cause heating, as obviously higher speed will produce higher friction and may demand the selection of a more quick-acting or higher quality oil to give good results.

If the *load* on an engine is *increased*, it is not unusual to find that some of the bearings are not able to sustain the increased strain and, therefore, heat.

Excessive strains in the bearings may also be produced by the settling of foundations, which throws the bearings out of alignment.

Excessive vibration may produce similar results.

Light load on a steam engine may cause heating of the crankpin bearing, there being an insufficient quantity of steam in the cylinder properly to cushion the movement of the heavy piston, so that the crankpin is subjected to excessive pressures.

Eccentric straps may heat on account of bad internal lubrication, which increases the resistance in moving the steam or exhaust valves.

Driving belts and ropes after a time become slack and must be shortened. If they are shortened too much, they produce *excessive pressure* on the bearings supporting the pulleys over which the belts or ropes run.

Excessive moisture in the atmosphere causes cotton belts or ropes to shrink, whereas leather belting stretches.

In textile mills where a number of the high-speed spindles are operated by cotton tapes and bands, the shrinkage of the cotton due to excessive moisture puts *excessive pressure* on the spindle bearings and causes heating.

Increased temperature will thin the oil, so that it may not be able to withstand the bearing pressures; for example, a new addition to a boiler plant in close proximity to the powerhouse increased the temperature of an engine room so much that all bearings heated until an oil heavier in body was introduced.

Excessive load on an electric motor or the electrical part's being out of order will cause high temperature in the rotor; the extra heat thus conducted into the bearings may cause the oil film to break down, indicated by excessive heating.

In many classes of rough machinery, it is still frequent practice to replace bearings without any attention's being given to *scraping them together with the shafts;* in fact, the bearings are allowed to "run themselves in," developing considerable heat and necessitating a liberal feed of heavy-bodied oil during the first few days. Needless to say, this is a crude and undesirable practice.

Whenever a bearing has been excessively hot, the *bearing brasses warp,* the cheeks of the brass closing against and nipping the shaft; it is necessary to file away and *chamfer the edges* so as to facilitate the entrance of the oil.

Cracked bearing brasses allow the oil to leak away; the oil film is destroyed, and even with a liberal oil feed the bearing will be sensitive and inclined to heat.

Too soft white metal often causes heated bearings, as it yields to the pressure and slowly flows out of the bearings, so that the bearing surface constantly changes and never assumes a good working skin.

Too hard bearing metal frequently results in heating, because the bearing pressures are not uniformly distributed over the surfaces.

Rebabbitting of a bearing should be done in one pouring; if done in two, the white metal already in the bearing will have partly solidified and will not melt properly together with the white metal poured in last. The result will be that in operation cracks will develop, and the white metal will break loose. This also occurs when the white metal has been poured too cold, as it does not adhere closely to the shell.

After a bearing is rebabbitted, the bearing edges should be rounded off, and all necessary *oil holes and distributing grooves properly made.* Failure in these respects will cause heating of the bearing.

If appreciable wear takes place, the edges of the *oil grooves become sharp* and act as oil scrapers rather than oil distributors. The edges must be kept well rounded, and the oil grooves should therefore occasionally be examined, particularly if trouble has occurred.

When worn bearing brasses have been replaced, the bearings sometimes heat because the new brasses have not been properly fitted or scraped together.

With crankshafts and the like which have recessed journals for the main bearings provided with filleted corners, heating may occur if the shaft has *insufficient room to float sideways,* as the shaft will bear hard against the fillet; expansion of the shaft may be the cause of this kind of heating; another cause is mentioned on page 167 for electric dynamos.

If the *bearing clearance is too small,* through too close adjustment, heating will occur, as there is insufficient room for the oil to produce a satisfactory film, and it becomes difficult for the oil to spread.

If the *adjustment of a bearing is too loose,* the oil escapes from the bearing too freely; and particularly in the case of bearings like crankpin bearings, which are subjected to intermittent heavy pressures, the oil will not be able to give sufficient cushion-

ing effect to prevent metallic contact; pounding or knocking of the bearing takes place, resulting in heating and wear.

In *starting up* after a stoppage, say over Sunday, certain bearings may be inclined to heat, as the power necessary to drive the mill or works is always a good deal higher than normal.

When *engines and machinery have been shut down for a longer period*, very special attention should be given to the lubricators and lubrication of all parts before starting operation again; driving belts and ropes are stiff after the long standstill, and it must not be expected that the plant can be quickly run up to speed without trouble.

Excessive deflection of a shaft due to various causes will result in overheating of the nearest supporting bearings, as the shaft will bear more heavily on one side of the bearings, the heat developing and spreading from here.

When *bearings of electric motors or generators wear*, the slight lowering of the rotor due to this wear will cause the magnetic field to exert a strong downward pull on the rotor, thus increasing the tendency to wear and causing excessive heating.

Where *oils of vegetable or animal character*, or at least heavily compounded oils, have been used, and where the new oil introduced is straight mineral or nearly so, the change-over should take place gradually, as vegetable and animal oils produce a sticky, varnish- or rubber-like coating all over the bearing surfaces and in the oil pipes. *If the change is made quickly*, heating is bound to occur or even seizure of the bearing surfaces, as the coating is loosened in lumps or flakes, preventing proper oil-film formation. It takes time for the bearing surfaces to adapt themselves to the new oil.

When *introducing a new oil* that is appreciably different in character from the oil previously in use, it will nearly always be found that some bearings heat up. This may be due to a mineral oil's dissolving deposits produced by a compounded oil, which on being too quickly loosened cause trouble, acting in the same way as grit or dirt.

The use of a *grease* containing dirt (which is not visible, as in oil) and impure graphite tends to choke oil pipes and oil grooves and is often responsible for heated bearings.

It is not unusual to find that a number of bearings in a mill are *using an oil far too heavy*, because a few bearings, operating under

bad mechanical conditions, have demanded its use to prevent overheating. It would be better economy to use the heavy oil on these few bearings only or, better still, to correct the mechanical conditions so that the proper grade of oil can be used throughout.

Cooling Heated Bearings.—When *small bearings* heat up, they are usually easy to cool down, as the total amount of heat present in the bearings is not very great; usually, a liberal supply of the oil in use is all that is required; if the bearing is heated to such an extent that it has been distorted or the white metal has started to flow, it must be dismantled and put in thorough working order.

When *large bearings* heat up, the case is very different, as large bearings may absorb and contain a great deal of heat; and when once a large journal starts heating and expanding, there is relatively so little clearance that the oil film is easily squeezed out, and the bearing may seize. The first thing to do when a large bearing heats up is therefore to increase the bearing clearance by slacking the bearing brasses.

If the bearing has not seized but is only extremely hot, it is usually sufficient to feed it with a liberal supply of steam-cylinder oil (which possesses superior lubricating properties under high temperature) until the bearing cools, when gradually the normal practice of oiling the bearing can be reinstated.

If the bearing has begun to seize, a little graphite, talc, flowers of sulphur, white lead, salt, Sapolio, or like ingredients mixed with cylinder oil may be used, as these solid substances help to smooth down the parts that have started to cut, thus enabling the cylinder oil to form a film. Even more drastic "remedies" like brick dust or grindstone dust have been known to cool bearings, when more greasy ingredients failed to separate the surfaces.

Castor oil is often employed for cooling bearings but should be avoided where a circulation system is employed, because it mixes with the engine oil and afterward develops deposits. Once a bearing has become accustomed to the use of castor oil, it is not always a simple matter to change back to the original conditions.

The practice of *using water for cooling the bearings* from the outside is very undesirable, as the result of the sudden cooling is nearly always distortion of the bearing brasses, so that they

have to be filed and scraped before satisfactory operation can again be expected.

LUBRICATION

The object of bearing lubrication is (1) to form a lubricating film between the rubbing surfaces and thus *replace the metallic friction with fluid friction,* as far as possible; (2) to *reduce the fluid friction in the oil film itself* to the lowest safe point, considering the operating conditions.

No Lubrication.—If a journal revolves in its bearing without lubrication, metallic contact will cause abrasion of the metal, and the bearing will not operate very long before the frictional heat developed will be so great that the bearing surfaces will be destroyed.

Oilless bearings are an exception; they are made of a metal alloy or compressed wood, mixed with graphite, talc, or other solid lubricant; or the graphite is firmly placed in the bearing in the form of spiral grooves or strips; or, again, the whole bearing may be compressed talc, soapstone, or graphite. Such bearings will often run without lubrication and without seizure, but the friction is very high, as is also the bearing temperature.

Boundary Lubrication.—By introducing a lubricating medium between the rubbing surfaces, the lubricant will adhere to the journal as well as to the bearing, thus replacing part of the metallic friction with fluid friction; there will be less abrasion, therefore less wear, friction, and heat.

The vast majority of bearings are boundary lubricated; *i.e.*, the rubbing surfaces are never kept completely apart, so that more or less wear does occur, and the loss in friction is not so low as it might be.

As all fixed oils are more oily than mineral oils, an admixture of a small percentage to the mineral oil will increase its oiliness and assist in separating the rubbing surfaces more completely.

If it were not for the high price of fixed oils and their tendency to gum (particularly the vegetable oils), they ought to be much more widely used than they are at present. It is particularly for heavy pressures and slow speed that great oiliness is so very desirable, necessitating the use of fixed oils. It is a well-known fact that castor oil and rape oils are extremely useful for very severe conditions of this kind.

Compounded oils also have the property of combining and emulsifying with water, so that their use is desirable where water gains access to the bearings. Water will displace a straight mineral oil and cause trouble but will combine with a compounded oil and form an emulsion or lather, which, particularly in the case of marine steam engines, is very desirable. If a bearing under such conditions heats up, the lather escaping from the bearing will lose its milky appearance and become semitransparent, this being an indication of excessive bearing heat.

Compare remarks under "Textile Machinery," "Marine Steam Engines," "Locomotives," "Stainless Oils," etc.

Oil-film Lubrication.—By introducing a sufficient quantity of oil it is possible to form between the rubbing surfaces a complete oil film, which means that there will be no wear and that the friction developed is reduced entirely to the fluid friction within the oil itself. Given the necessary surface speed, a suitable bearing pressure, and the required flow of oil, as will often be the case with circulation-oiling, ring-oiling, and bath-oiling systems, the friction is entirely fluid friction determined by the viscosity of the oil, the surface speed, and the area of the rubbing surfaces; oiliness is of no importance (except when starting and stopping); the viscosity alone is what maintains the oil film. The higher the viscosity the more easily will the film be formed at low speeds; but at high speeds, high-viscosity oils may give trouble, and low-viscosity oils should always be preferred.

SELECTION OF OIL

In order to obtain efficient lubrication, oils must be selected to suit the operating conditions and the oiling system employed.

Operating Conditions.—The oil must be selected to suit the conditions of size, speed, pressure, temperature, and mechanical conditions.

Speaking generally, *oils light in body* should be employed for such conditions as small bearings, high surface speed, low bearing pressure, low room temperature, and good mechanical conditions.

Speaking generally, *oils heavy in body* should be employed for large bearings, low surface speed, high bearing pressure, high room temperature, and bad or indifferent mechanical conditions.

Oiling Systems.—The oil must also be selected to suit the oiling system employed.

Hand Oiling.—Hand-oiled bearings are rarely well lubricated; they are usually only boundary lubricated and demand the use of heavier bodied oils than would be required with a more efficient oiling system. This system wastes both oil and power. Unless the waste of oil is very abnormal, compounded oils should be preferred for hand oiling, as such oils have greater oiliness than straight mineral oils, therefore last longer and give less friction.

Drop-feed Oiling.—In drop-feed oiled bearings, less oil is wasted than in hand-oiled bearings, and, owing to the more regular oil feed, the oil film in the bearings is kept more uniform and more complete; the lubrication is therefore more efficient; *i.e.*, there is less friction and less wear. Under high-pressure conditions, compounded oils should preferably be used; for low or moderate pressures straight mineral oils will render good service.

Ring Oiling.—By the ring-oiling system the bearing surfaces are constantly flooded with oil, so that the lubrication becomes as efficient as possible with the particular grade of oil in use. Straight mineral oils should be used, as compounded oils will cause gumminess on the oil rings and in the bearings.

Splash Oiling.—The oil should be light in body so as to splash easily to all parts yet sufficiently heavy to produce satisfactory lubrication.

Circulation Oiling.—As the oil is forced in large quantities to the bearings, it is given every assistance to produce complete and perfect lubrication, and the heat is so rapidly removed that it becomes possible to operate engines employing this system at the highest speeds and yet maintain a great margin of safety in operation. The oil must, however, be of such a character as to maintain its nature, notwithstanding that it circulates continuously and is exposed to the oxidizing influence of air and impurities, the emulsifying influence of water, etc. Also, it must be of such a nature as to separate quickly from water and impurities, so that sludge or deposit developed may be easily removed from the oil in circulation. As to the nature of such oils—circulation oils—see remarks under "Turbine Lubrication" (page 243).

The best oils used in splash oiling, ring oiling, or oil-bath systems possess similar characteristics.

Where hand oiling or drop-feed oiling systems are employed, the oil, after passing through the bearings once, is frequently run to waste and not used over again, in which case the slight alteration that takes place in the oil passing through the bearing is of no importance, and compounded oils can be used without trouble.

When the oil, after passing through the bearings, is collected and filtered for the purpose of using it over again, either on the same bearings or for less important work, mineral oil may be preferred, particularly if it be used over and over again a great number of times on important bearings and with only slight loss.

Selection of Oil.—It will now be understood that when selecting oils for bearings operating at high speed, with low bearing pressures, and employing a good lubricating system, the chief object should be to reduce the fluid frictional losses, as here the question of wear is less apt to become an important factor.

For high-speed spindles in textile mills, high-speed shafting, and machinery of many types, oils of the correct *light body* and quality should therefore be selected, and the result will be an appreciable reduction in power.

In bearings operating at slow speed, with heavy bearing pressures and using a less efficient oiling system, the danger of wear is great, and the chief object of lubrication here becomes minimization of wear, rather than the reduction of fluid friction.

For such bearings as are employed in large open-type steam engines, heavy pumping plants, and heavy machinery bearings, oils of the correct *heavy body* and quality should be selected.

There are many plants in which it is declared that there is no trouble. Whether this be so or not, there is a long distance from this no-trouble standpoint to perfection in operation; it is only by analyzing the actual conditions, carefully grouping various portions of the machinery and using specially selected oils for each group to give maximum lubrication service, that perfect results can be obtained and maintained.

There are many types of modern machinery, such as steam turbines, high-speed steam engines, internal-combustion engines of all kinds, and other high-speed machinery, where the conditions demand the use of the highest quality oil obtainable, almost regardless of its cost, and where smooth and safe operation and low frictional losses count many times more than the cost of the oil itself. On the other hand, where the class of machinery

in use is rough or in bad repair, where wasteful and inefficient oiling systems are employed, and particularly where the care and attention given to the plant are indifferent or bad, it is not always possible to justify the use of the best quality lubricating oils. So much oil may be wasted to no useful purpose that the cost of the oil thus literally thrown away will more than outweigh the value of the better lubrication that might be brought about by the use of better oils.

BEARING OILS

To satisfy the bearing requirements of the great variety of engines and machinery in existence, a great number of bearing oils are needed. Many of these oils will be mentioned under the class of machinery for which they are recommended, *e.g.*:

Circulation oils	For steam turbines, enclosed-type steam engines, etc.
Marine-engine oils	For marine steam engines and other severe service
Loco engine and car oils	For locomotives, tenders, and cars
Spindle and loom oils	For textile machinery
Black oils	For mine cars and rough machinery
Steam-cylinder oils	Used for bearing lubrication of enclosed-type, splash-oiled steam engines

In all these cases there are service conditions that call for some special property in the oil and therefore justify grouping such bearing oils in the way indicated above.

With *bearing oils* the author proposes to refer to oils intended to be used and recommended for all types of machinery, where the service conditions do not present any specially difficul features.

In other words, bearing oils are oils whose prime duty it is to lubricate and which are not required to withstand oxidation or emulsification (as circulation oils) or to lubricate heavy bearings in the presence of water (as locomotive- and marine-engine oils) or to possess stainless properties (as loom oils), etc.

Bearing oils are oils ranging in color from light to deepest red; they must be refined but need not be specially well refined; in fact, excessive acid treatment or earth filtration removes many active unsaturated hydrocarbons, some of which are quite as good as if not better lubricants than the saturated hydrocarbons.

A certain degree of refining is, of course, needed to remove a sufficient amount of the most unsaturated elements which, if left in the oil, would cause excessive gumming in the bearings.

The oiliness of distilled mineral lubricating oils can be improved by admixture of a small percentage, say from 5 to 10 per cent, of fixed oil or a certain percentage of filtered cylinder stock. To make this point clearer, the author has found that when using oils compounded in this manner, (*i.e.*, admixture of fixed oil or filtered cylinder stock), lower viscosity oils can be selected to render certain service than if a distilled mineral lubricating oil were to be employed; the result is, therefore, lower friction and wear.

Such savings in power accomplished by using lower viscosity compounded oils are mentioned on page 330 for textile machinery. In the same way, power savings can be obtained by replacing a distilled mineral oil of a certain viscosity by a lower viscosity oil, which is made by mixing a spindle oil (or a blend of a spindle oil and a medium red oil) with a certain amount of filtered cylinder stock.

Without going more deeply into this matter the author gives below approximate viscosities (see table, page 57) for six bearing oils, which will be found to cover a wide range of service.

LUBRICATION CHART
For Bearings

Bearing oil number	Viscosity number	Approximate absolute viscosity, in centipoises, at 50°C.	Recommended for
1	3	10	Very light duty and high speed
2	4	13	Light or medium duty and medium or high speed
3	6	20	Medium duty and medium or high speed
4	7	26	Medium or heavy duty and medium or high speed
5	9	56	Heavy duty and slow or medium speed
6	10	76	Heavy duty and slow speed

The author hesitates to give the foregoing service recommendations, which of necessity are very crude, but under the various sections on engines and machinery following this chapter he has endeavored to convey his ideas and experience in a more definite manner.

SEMISOLID LUBRICANTS

The various methods by which semisolid lubricants are applied may be classified as follows:

Contact feed.
Stauffer cups.
Compression cups.
Mechanical feed.
Grease bath.

Contact Feed.—By this method the grease is placed direct on the journal, *e.g.*, in the dryer bearings of paper machines and the roll-neck bearings in steel mills. The grease adheres to the journal, melts away or softens, and gradually wears away. Hard greases are generally employed. With soft greases the consumption is usually great, particularly when the bearing is worn, as in that case the grease adhering to the journal is pulled into the large clearing space between the journal and the keep and is quickly consumed.

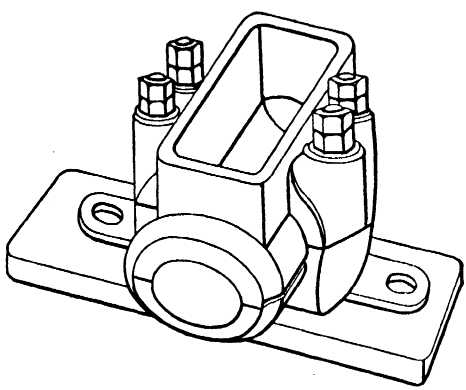


FIG. 21.—Contact-grease-feed arrangement.

When soft grease is applied direct to the shafting it must be protected by a layer of yarn-fiber grease, *e.g.*, in shafting bearings for weaving sheds and in bearings used in connection with the rollers that support rotary kilns in cement works. Such bearings have a large cavity at the top (Fig. 21); the yarn grease is placed all around the walls of this cavity, and sometimes also there is a bottom layer touching the journal. In the pocket thus formed is placed ordinary cup grease or fiber grease, the grade being selected in accordance with the temperature conditions; exposed

to the heat, the grease in the pocket melts slowly through the yarn grease and lubricates the journal.

Figure 22 shows a gravity-feed grease cup designed for the use of low-melting-point greases or oils, which are slightly soap thickened, so as to be nonfluid at ordinary room temperatures. The needle, in touching the shafting, gets warm, melts a little of the grease and acts very much like the needle in glass bottle oilers (Fig. 17, page 115).

Stauffer Cups.—Figure 23 shows an ordinary plain cup; the bottom is preferably sloping to facilitate the grease's being forced out of the cup. The cover is given an occasional turn, and a quantity of grease is forced into the bearing; it is gradually consumed until the cover is given another turn. To prevent thin grease from leaking out, the thread must be a good fit, or a leather packing must be introduced as shown in Fig. 24. This drawing also shows a catch pawl which prevents the cover from slacking back.

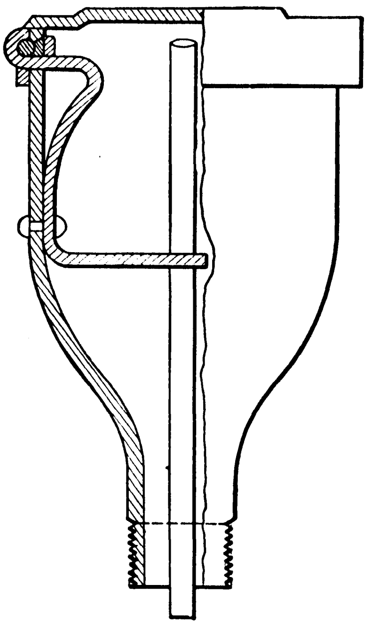
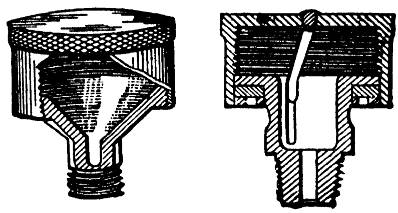


Fig. 22.—Gravity-grease-feed arrangement.



Figs. 23–24.—Stauffer cups.

Compression Cups.—Compression cups may be operated either by a spring or by compressed air. Figure 25 shows a typical spring compression cup. The spring (1) pushes against the piston (2). The feed can be adjusted by the screw (3). Only greases of No. 1 and No. 2 consistency can be used in this type of cup.

For harder greases of No. 3 or No. 4 consistency, a grease cup must be used like Phillips crankpin grease cup shown in Fig. 26. By turning the milled collar (1), grease is forced up into the small cylinder (2), raising the piston against the force of a strong spring, which subsequently feeds the grease until the indicator knob (3) shows that another feed must be given.

Figure 27 illustrates the Menno compressed-air cup in which compressed air is employed for forcing out the lubricant. The lubricant is filled into the bottom portion (1) of the cup; this part is threaded to receive the upper portion (2), which on being screwed into the lower portion causes a certain air pressure to be formed above the grease. The object of the thin metal disk (3), which is guided vertically, is merely to rest on top of the grease and keep it level. The fixed disk (4) forms the top of the air-

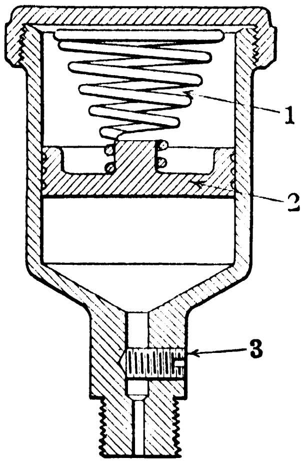


FIG. 25.—Spring compression cup.

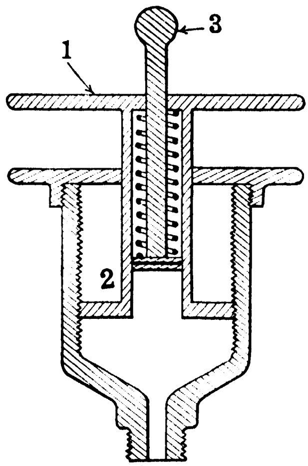


FIG. 26.—Phillips crankpin grease cup.

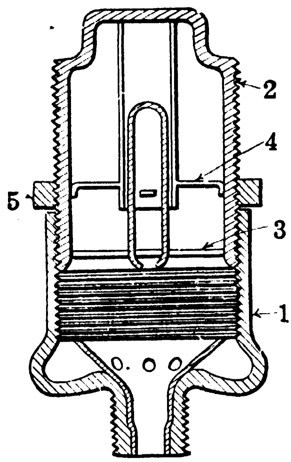


FIG. 27.—Menno grease cup.

compression chamber. After giving the upper portion (2) a certain number of turns, it is locked to the bottom portion by means of a lock nut (5) and the air pressure will maintain a fairly regular feed. If the journal gets warm, the heat is conducted up into the cup through a thin funnel. The effect of this rise in temperature is to soften the grease, increase the air pressure, and give an increased feed of lubricant.

In grease cups for lubricating loose pulleys the centrifugal force acting on a piston may be made use of to force thin grease, or nonfluid oil, to the bearing.

Mechanical Feed.—In very large colliery winding engines or steelworks rolling-mill engines, hard greases, usually white, may be forced into the crankpins by means of mechanically operated lubricators, as indicated in the sketch (Fig. 28).

The arrangement is very similar to the banjo oiler. A cam on the feed pipe (3) operates a ratchet lever (4). The motion of

the ratchet wheel (5) and worm gear (6) actuates a piston (7) which forces the grease below the plunger through the feed pipe (9) into the crankpin. Another method is to place the lubricator complete on the crankpin itself. The lever (4) is then weighted at its lower end and swings to the right and left between two adjustable stops, owing to the motion of the crankpin. The lever in this way oscillates sufficiently to operate the ratchet, and the feed may be adjusted within certain limits, say one, two, or three teeth per revolution.

The advantage of a mechanical feed as against compression cups is that the lubricant, whether soft or hard, is delivered

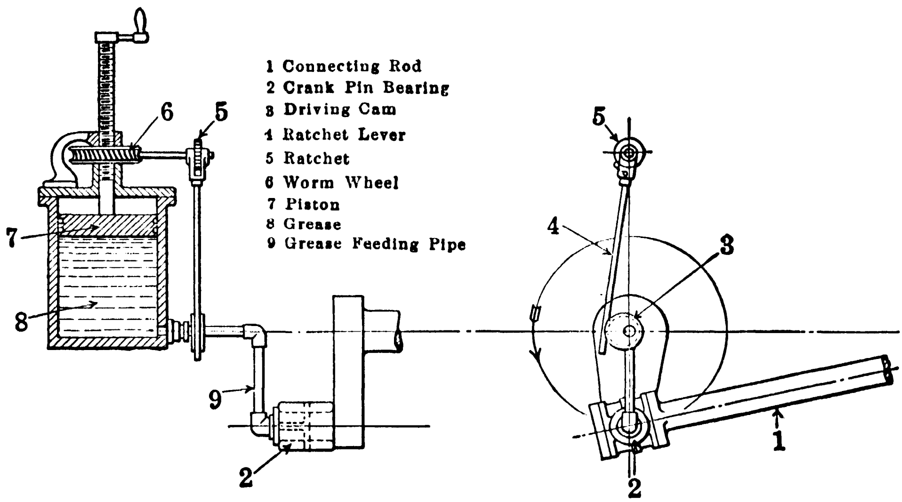


FIG. 28.—Mechanical grease lubricator.

absolutely uniformly, notwithstanding changes in temperature which either harden or soften the grease and the result of which with ordinary grease cups is that a uniform feed cannot be maintained.

Grease Bath.—A bath of grease may be employed in connection with ball and roller bearings, gearboxes of automobiles, gear chambers in pneumatic tools, etc.

The reasons why grease is employed are outlined under these several headings and are mainly to keep dust or grit out of bearings or to prevent excessive leakage of lubricant.

Greases of Nos. 1 and 2 consistencies are used for grease baths; harder greases create undue friction, are inclined to cake exposed to heat, and do not distribute themselves with sufficient ease.

GREASE LUBRICATION IN GENERAL

The conditions for which semisolid lubricants are advantageously employed will be indicated in the following, fuller information being given under the various sections of machinery, etc., referred to.

In *dusty and dirty surroundings, e.g.,* cement mills, bakeries, colliery screening plants, etc., grease keeps the bearings clean; it entirely fills the bearing cavities and the clearance space and forms a fillet round the bearing ends, which prevents the entrance of dust and dirt. This is particularly important for ball and roller bearings.

When oil is used in *weaving sheds,* it is necessary to fix save-alls below the bearings. For this reason, grease is sometimes preferred to oil, because there is less likelihood of the spent lubricant's dropping from the bearings on to the looms and soiling the goods.

When bearings are in *inaccessible places* and cannot be lubricated with oil by ordinary means, grease cups can be fitted, and the grease forced through tubes into the bearings from any angle.

Greases of high melting point—fiber greases and others—are required occasionally where the bearing temperatures or room temperatures are unusually high, such as the hot necks on dryers in paper mills, hot journals supporting the rotary kilns in cement works, and hot-roll necks in tin-plate mills and steel mills.

Grease should be used only where there are special reasons against the use of oil. Wherever grease is used under conditions that are quite suitable for oil lubrication, the introduction of the correct grade of oil will always result in an appreciable saving in power. Grease lubrication means a heavy frictional resistance in the bearings, as obviously the grease does not begin to lubricate until the frictional temperature has increased to such an extent that the grease melts or becomes sufficiently soft to be "abraded" by the revolving journal.

The suitability of a grease depends on four things:

1. The purity of the grease and the absence of filling matter.
2. The consistency of the grease (to suit the method of application).
3. The quality of the oil and other ingredients in the grease.
4. The melting point of the grease (to suit the temperature conditions).

Purity is very important in greases that are used under conditions of high pressure or speed. Such greases should preferably be strained hot as mentioned (page 25).

Filling matter is nonlubricating; it lowers the manufacturing cost of grease but usually detracts from its lubricating value. For rough mechanical conditions or for very high bearing pressures and slow speed, filling matter like graphite, talc, or mica may, however, prove advantageous, helping to fill up unevenness in the rubbing surfaces and preventing seizure. Filling matter containing gritty or hard impurities will cause wear but may prove beneficial as a temporary remedy in the case of hot bearings.

Consistency.—The consistency of grease is largely governed by the feeding appliances. If grease is applied through compression cups or gravity-feed cups, it must be soft, either No. 1 or No. 2 consistency, also when used for high-speed bearings and ball and roller bearings.

For Stauffer cups, No. 2, 3, or 4 consistency can be employed.

A grease of No. 4 or 5 consistency may be selected for contact-feed application in connection with slow-speed open bearings, the grease resting directly on the rotating shaft.

Quality.—The quality of grease depends largely on that of the lubricating oil used in manufacture.

For medium- and high-speed work, with no excessive bearing pressures, a grease should be chosen that contains a light-bodied lubricating oil.

For medium- and slow-speed work with fairly heavy bearing pressures, the grease should preferably contain a more viscous oil; and for extreme conditions of pressure and slow speed, fatty oils or fats must form part of the grease, as great oiliness is required. A percentage of solid lubricants may also be of advantage, as mentioned under "Filling Matter."

Changing Grease.—When a change is made from white and other greases that contain much tallow or other fat or fatty oils to a mineral grease, as cup grease, the process must be gradual to avoid heating, this being just as necessary as when changing from, say, castor oil to a mineral oil.

SOLID LUBRICANTS

In order to determine the proper range of service for the various solid lubricants in the field of lubrication, the subject will be divided into the following sections:

Theory of the Action of Solid Lubricants.
Methods of Application and Use.
Observations on Results Obtained by the Use of Solid Lubricants.

In order to avoid having to refer repeatedly to the use of solid lubricants throughout the book, the author has at this place dealt with the entire field of service for solid lubricants in such a manner that further references to this subject may perhaps be considered unnecessary.

THEORY OF THE ACTION OF SOLID LUBRICANTS

It is generally agreed that the friction created in engines or machinery of all kinds is composed chiefly of what may be termed solid friction or fluid friction or a combination of both, the latter condition representing the state of affairs in the great majority of cases.

In the following, the influence of solid lubricants on each of these various kinds of friction will be dealt with separately. Reference will also be made to the use of solid lubricants for treatment of hot bearings.

Solid Lubricants and Solid Friction.—When a solid lubricant is introduced between otherwise unlubricated surfaces, the more or less finely divided particles of the lubricant associate themselves with one or other of the rubbing surfaces, filling in the pores and depressions and acting, as far as possible, as a smoothing and polishing agent, covering the original surfaces with a thin, smooth layer of the solid lubricant. As a result, the coefficient of friction is reduced; the solid friction between the more or less rough original rubbing surfaces is replaced by the lesser solid friction between the smooth surfaces formed by the solid lubricant.

When abrasion takes place, it occurs not so much between the original surfaces (which possess great cohesion) as between the particles of the solid lubricant, which have but little cohesion. Artificial amorphous graphite, for example, has practically no cohesion. If solid lubricants are employed, cutting and abrasion of the bearing surfaces are therefore much less likely to occur.

There are a variety of conditions for which dry solid lubricants have proved advantageous, *e.g.*, in bearings or in such parts of machinery as are apt to be neglected from a lubricating point

of view, and that operate at *low pressures and low speeds.* When such surfaces are well coated with graphite, for example, and particularly if they are rubbed down to a dense glazed finish, they will work upon each other for a long time with comparative freedom and without danger of cutting or wear's taking place.

Solid Lubricants and Fluid Friction.—The application of solid lubricants to bearings in which a perfect oil film is established would at first sight appear to be of no value; the journal floats on a film of oil, and the presence of small particles of a solid lubricant does not increase the viscosity to any appreciable extent. The friction under running conditions is therefore not increased unless the solid lubricant is present in such an amount that the particles "crowd" the oil film at the "point of nearest approach" between journal and bearing and start to act as an abrasive powder.

It has repeatedly been noticed in experimental work that immediately after a temporary application of solid lubricant in powder form, the friction is much increased but is reduced afterward, when the particles have had time to attach themselves to the rubbing surfaces and form a smooth coating. *The virtue in the employment of a solid lubricant lies entirely in the effect that it produces on the rubbing surfaces themselves.* With perfectly lubricated bearings the chief advantage of using a solid lubricant is apparently the effect on the friction at the moment of starting, which results in a reduction in the static coefficient of friction.

Static and Kinetic Friction.—The effect of the use of a suitable solid lubricant or a solid colloidal lubricant is, as we have seen, to reduce the tendency to abrasion and to produce a smoothness of the surfaces. As the solid lubricant cannot be displaced by pressure, the static coefficient of friction is reduced as compared with the result obtained when oil alone is used, assuming that the solid lubricant is of such a nature and used in such a manner that it has actually increased the smoothness of the rubbing surfaces.

Solid Lubricants and Boundary Lubrication.—Under these conditions there appear to be great possibilities for the use of solid lubricants. Their object will be:

1. To reduce the solid friction.
2. To produce a smoothness of the rubbing surfaces, which will assist in distributing the load evenly over all parts of the bearing and thus enable a lower viscosity lubricant to be used and the fluid friction to be reduced.

3. To reduce the wear of the original surfaces and the risk of abrasion or cutting of the surfaces which ordinarily leads to the production of hot bearings.
4. To reduce the consumption of lubricant.

To obtain these advantages, the solid lubricants must be of suitable nature, purity, fineness, and hardness and must be used in the right amount.

Nature.—A good solid lubricant must possess ability to adhere to metallic surfaces, and it must be capable of producing a smooth surface. Graphite possesses both of these properties to a marked degree. When rubbed between metallic or nonmetallic surfaces, graphite whether of the flake or of the amorphous variety produces a coating that is smooth and unctuous. Talc and mica do not adhere to surfaces so well as graphite does, nor do they produce so smooth a surface.

The quality of unctuousness in the surface produced is undoubtedly important; it is not possessed by materials such as flowers of sulphur or white lead, which act more as abrasives than as lubricants.

Purity.—A high degree of purity of the solid lubricant is necessary in connection with lubrication of all high-class machinery; whereas for rough bearings operating under extreme conditions and on the verge of seizure, a small amount of impurities may not be detrimental.

Fineness.—In the case of well-finished rubbing surfaces, very finely divided graphite must obviously be used, and the coating is easier to accomplish than with rough surfaces. Under these conditions, makers of amorphous graphite claim that a flake graphite when used in excess is apt to build up too thick a surface and reduce the working clearance to a dangerous extent, whereas with amorphous graphite, excessive use can have no ill effects; the soft, crumbly, amorphous grains are easily crushed; in fact, a surface of fine amorphous graphite under pressure moves within itself like a film of oil, and the particles are noncoalescing and offer little resistance to movement.

With highly finished and polished surfaces operating with small clearances it would seem undesirable to use powdered lubricants, however finely they may be pulverized. Colloidal lubricants appear to be the only solid lubricants likely to give satisfaction under such conditions.

Hardness.

HARDNESS OF SOLID LUBRICANTS

	Relative Hardness
Pure graphite	1.0
Best quality of talc	1.0
Lower qualities of talc or soapstone	2.5 to 4.0
Micas	2.0 to 3.0

The admixture of a hard solid lubricant, like hard talc or mica, to a grease, particularly if an excessive amount is added, may cause a great deal of continuous but uniform wear—much more than would be caused by the grease used by itself—yet no cutting or excessive heating of the bearing may occur.

Amount.—Makers of flake graphite recommend the admixture of 3 to 4 per cent of fine flake graphite with oil; if too much graphite is used, the friction is increased, because more graphite is introduced into the bearing than is required to keep the rubbing surfaces properly graphited. The surplus graphite present between the rubbing surfaces creates extra friction and heating.

If appreciably less graphite is added than 3 per cent, a point will be reached when the graphite coating will no longer be fully maintained, and the full benefits from the use of graphite will not be obtained.

Makers of graphite greases recommend a percentage of graphite ranging from 3 to 10 per cent. More graphite is required with grease than with oil, because grease is usually employed for rougher conditions than oil, and more graphite is needed to build up the surfaces and maintain them in a smooth condition.

The effect of adding a solid lubricant to a lubricating grease is that in time the solid lubricant will attach itself to the rubbing surfaces and, by smoothing and polishing them, will make it easier for the lubricant to do its duty. As a result, a softer grease or a grease containing a lower viscosity oil can be employed than when no solid lubricant is added to the grease.

Makers of colloidal graphite find that a very small percentage of graphite is ordinarily required in the diluted colloidal lubricant. Acheson recommends a graphite content of 0.35 per cent for most purposes. That this small amount has been found sufficient is probably explained by the fact that colloidal lubricants are used chiefly on high-class machinery with reasonably well-finished bearing surfaces.

Hot Bearings.—Hot bearings may be caused by excessive stresses or vibrations, by the accidental entrance of gritty impurities, by a shortage of lubricant, etc. Whatever the cause may be, the oil film becomes entirely displaced from a small portion of the bearing surface; a "dry" spot is formed; the surfaces enter into intimate metallic contact; the local temperature rises rapidly; the bearing seizes; and, if it is lined with white metal, the latter may melt and flow out. Under such conditions, when a bearing gives warning by heating, the usual procedure is to resort to the use of a fixed oil, like castor or rape oil, or to a viscous mineral oil, like steam-cylinder oil; the effect of using such oils is to produce a better film, which separates the metallic surfaces and reduces the temperature.

When the surfaces have begun seriously to abrade one another, oils may prove of no avail, and solid lubricants must be used, such as graphite. The graphite particles by coating and impregnating the surfaces make it difficult for the metallic surfaces to seize; and if slight abrasion takes place in certain places, the graphite may often succeed in repairing the damage and make it possible for the normal lubricant again to take care of the condition.

Flowers of sulphur and white lead are often used to cure hot bearings; they act not so much as lubricants but rather as mild abrasives; they grind away the rough spots and produce a smooth surface.

Much more drastic remedies, such as salt, brick dust, and grindstone dust, have been successfully employed in very serious cases of large hot bearings; their function is to grind away quickly the rough parts that have begun to seize. They may be applied mixed with thick steam-cylinder oils or castor oil, in order to produce a thick film. The oil should be applied liberally in order to clean away the gritty powder after it has done its duty.

In bearings that are inclined to run hot, it is good practice occasionally to apply a small amount of graphite to produce a graphitized surface or to mix colloidal graphite with the normal lubricant, so as continuously to make up the wear on the graphite coating. In overloaded worm gears, for example, which are continuously inclined to seize, it is good practice to mix a small amount of flowers of sulphur or fine graphite with the oil; they serve to prevent seizure, and the wear becomes more uniform.

METHODS OF APPLICATION AND USE

Solid lubricants may be applied in three different ways:

1. Dry application.
2. Mixture of solid and semisolid lubricants.
3. Mixture of solid and liquid lubricants.

Dry Application.—Solid lubricants are applied dry in cases where for special reasons it is inadvisable or impossible to use an ordinary liquid or semisolid lubricant. The finely powdered solid lubricant is put into a linen bag, and the bag is pounced or struck against the parts requiring lubrication; or a syringe like that used for applying insect powder may be employed to inject a cloud of lubricating powder into the bearings.

The following examples are illustrative:

Lacemaking Machines.—On certain reciprocating parts powdered graphite is used in place of oil, to avoid staining the fabric.

Bottle-making Machines; Galvanizing Machines.—Certain parts are exposed to extremely high temperatures; oil would burn away and leave a carbonaceous residue which would cause the parts to stick.

Chocolate and Candy Machinery.—To avoid oil's dropping into the chocolate or candy, all bearings may be lubricated entirely by dry graphite powder. The pressures and speeds are low, so that the friction developed is not too great for comfortable running.

Oilless Bearings.—Oilless bearings are referred to on page 130.

For the lubrication of rubbing surfaces made of wood, graphite is very suitable; it is not absorbed, as in the case of oil. The graphite may also be applied mixed with grease, for the sake of convenience of handling.

Steam Cylinders and Valves.—Dry graphite in the form of small cylindrical sticks has been used in conjunction with oil for lubricating locomotive valves and cylinders, the oil being supplied by a separate lubricator. The graphite sticks are placed in a vertical tube and rest upon an abrasive wheel, which obtains a rotative or oscillating motion from some reciprocating part of the engine, *e.g.*, the valve rod. In this way, the abrasive wheel continuously abrades the bottom graphite stick, and the graphite powder drops down a vertical passage direct into the engine.

Mixture of Solid and Semisolid Lubricants.—The use of a solid lubricant in powder form is resorted to only in special

circumstances. When there is no particular objection to the use of a fluid or semisolid lubricant and it is desired to use a solid one, it is obviously desirable to mix the two together. Semisolid lubricants are eminently suitable as carriers for solid lubricants because, being nonfluid, they prevent separation of the graphite, and, as they are themselves gradually consumed, they automatically supply the solid lubricant to the parts that they lubricate.

The admixture of solid lubricant usually ranges from 3 up to 10 per cent, rarely exceeding the latter amount.

Speaking generally, semisolid lubricants are always improved by the admixture of a small amount of finely pulverized pure flake or amorphous graphite. Exceptions are bearings with highly polished surfaces and small clearances and high-class ball and roller bearings, for which colloidal solid lubricants are the only solid lubricants that can be considered.

Mixture of Solid and Liquid Lubricants.—Ordinary solid lubricants cannot normally be applied mixed with liquid lubricants, because, however finely the solids may be pulverized, their high specific gravity causes them to settle out in the lubricators, oil pipes, etc. The finer the particles and the more viscous the oil the more slowly does separation take place, so that slight agitation may be sufficient to prevent separation. Mixtures of very finely pulverized solid lubricants and viscous oils, such as gear oil for automobile gearboxes, may be kept mixed by the stirring motion set up by the gears.

Certain mechanically operated graphite-oil lubricators for steam engines are fitted with stirrers in the lubricator container as well as in the oil pipe leading from the lubricator to the engine, to assist in preventing the graphite and oil from separating.

This problem of preventing separation of the solid lubricant is one that is causing many difficulties and cannot be said to have been satisfactorily solved, on account of the mechanical complications involved.

Chapman and Knowles have patented a mixture of finely pulverized graphite and glycerin for lubricating steam-engine cylinders. Before being mixed with the glycerin, the graphite is impregnated with a sufficient amount of petroleum or other hydrocarbon insoluble in glycerin, to reduce the specific gravity of the mixture to that of glycerin. As a result, the "graphite-

petroleum" specks will remain in suspension in the glycerin, and the mixture can be pumped by a mechanical lubricator and supplied to the steam engine in the ordinary way.

Solid lubricants can, of course, be mixed with oil and, in the form of a more or less liquid paste, may be applied by hand to the bearings or parts requiring lubrication. This method is the one employed when "curing" hot bearings.

It would appear that the only really satisfactory way in which a solid lubricant can be automatically applied mixed with a liquid lubricant is to bring the solid lubricant into such a finely divided state that the particles become of a size approximating that of submicrons. This state of fineness cannot be obtained by mechanical means alone but has been attained by certain processes, such as Acheson's process already referred to. Colloidal solid lubricants, when diluted with pure oil (oildag, oleosol) or pure water (aquadag, hydrosol) do not separate out to any extent; they can be diluted indefinitely and can therefore be applied to any engine or machine, mixed with the diluent which serves as a carrier.

Archbutt[1] has made some siphoning tests with oildag and has proved that deflocculated graphite will pass over with lubricating oil through worsted trimmings with but little loss of its graphite content.

Many mechanical lubricators employ a sight-feed arrangement through which the drops of oil rise through a sight glass filled with water; no difficulty is experienced with oil containing colloidal graphite, as the surface of the oil is not penetrated by the water. It is different with watery solutions of colloidal graphite such as aquadag; they obviously cannot be passed through water. Johnston has patented a lubricator with a sight-feed glass filled with kerosene, through which the drops of diluted aquadag sink down on account of their higher specific gravity as compared with kerosene. This arrangement has proved quite satisfactory for feeding aquadag into the steam pipes of engines using saturated steam.

Drawbacks to the Use of Colloïdal Solid Lubricants.—One unsatisfactory feature of colloidal graphite solutions is their black, "inky" nature, which creates strong prejudice against their use on the part of operators of engines or machinery;

[1] Archbutt and Deeley, "Lubrication and Lubricants," p. 152.

colloidal graphite stains are difficult to remove from the hands, etc. Colloidal talc will probably prove less objectionable in this respect than colloidal graphite.

The great drawback to all colloidal solid lubricants is, however, their susceptibility to the action of electrolytes, *e.g.*, acids and alkalies. The presence of electrolytes causes rapid destruction of the colloidal films and flocculation or separation of the solid lubricant from the liquid in which it is dispersed. The following experiments with dilute diffusions of oildag and aquadag in oil and water, respectively, containing various percentages of mineral acid, alkali, fatty acid, acetic acid, and petroleum acid show the tendency to flocculation. The oil used for the oildag experiments was a neutral filtered spindle oil to which was added the amount of oildag recommended by the makers, giving a graphite content of 0.35 per cent of the blended oil. The results are as follows:

Mineral Acid.—It was found that even the slightest trace of sulphuric acid (H_2SO_4) precipitated the graphite. Flocculation within 24 hr. was caused by 0.1 per cent sulphuric acid; 0.005 per dent caused complete flocculation in 3 days.

Alkali.—The results with an alkali (caustic soda) were very similar.

Acheson himself has realized the importance of the purity of the mineral oils or water used for mixing with oildag or aquadag, respectively. He states:

With deflocculated graphite the very best results will be obtained when the water or oil is absolutely pure, but commercially we may perhaps always have a very slight sedimentation of the graphite. The manufacture of practically pure or neutral petroleum oil may be made quite commercial, the presence of impurities in the oil now placed on the market being almost solely due to the failure of manufacturers properly to wash the oil. True, in some instances, while thorough washing may be performed with water, the water itself is not pure, which would still cause impurities to be found in the oil that would be capable of causing sedimentation of the graphite, but this residue, which is left by natural waters when they be of an impure nature, could finally be removed by a finishing wash with distilled water.

It is a fact that most if not all acid-treated oils on the market are quite unsuitable for mixing with colloidal lubricants. The

most suitable oils are undoubtedly these which during the process of refining have not been in contact with acids or alkalies but are refined by earth filtration only. Users of colloidal lubricants should therefore be warned not to mix them with the ordinary grades of oils, unless they have the assurance of their suppliers that none of the ingredients present contains acid or alkali or has been acid treated.

Fatty Acids.—The flocculating action of fatty acid is not so marked as with mineral acid. The graphite was precipitated by 0.3 per cent of linseed-oil fatty acid in 4 days; 0.1 per cent of the same acid took 2 weeks to precipitate the graphite completely. Holde states that "free organic acid need not always act as a coagulant even with colloidal graphite; small quantities may under certain circumstances act as a stabilizer."

This experiment shows that, if precipitation of the graphite is avoided, colloidal lubricants should not be mixed with fatty oils or compounded oils that contain a fair amount of fatty oil.

Most oils used for marine steam engines, locomotives, and other severe services are heavily compounded with vegetable or animal oil (from 10 to 30 per cent) and contain an amount of free fatty acid, usually exceeding 0.5 per cent.

Acetic Acid.—The action of acetic acid was found to be similar in intensity to that of mineral acid.

Petroleum Acids.—Petroleum acids (of a fairly volatile organic character) may be produced, during use, in oils employed in circulation systems in automobile engines, gas engines, oil engines, and Diesel engines.

In the author's experiments, petroleum acid was produced in the oil by blowing air through neutral filtered spindle oil heated to a high temperature (360 to 400°F.) to accelerate the oxidation and the formation of acid. To the oil thus prepared was added the prescribed amount of oildag. The presence of 0.1 per cent of petroleum acid caused complete precipitation of the graphite in 5 hr. When the experiment was repeated with another sample of oil similarly treated, but only slightly "blown," containing 0.01 per cent of petroleum acid, the flocculating action was much less marked, but after 2 weeks complete separation took place.

The amount of petroleum acid produced in the oil during prolonged use in an automobile engine will not be very great. An

average amount may be considered 0.01 per cent, assuming that the oil is a neutral filtered oil; and as oils for automobile use are fairly viscous, there is perhaps not much to fear from the presence of petroleum acid. Obviously, the more viscous the oil is the more slowly does the graphite separate out.

Oils taken from enclosed high-speed gas and Diesel engines have been examined, containing over 3 per cent of free carbon in suspension, which had produced no ill effects on the engine. The carbon had been formed by carbonization of the lubricating oil inside the cylinders and had worked its way down into the crank chamber and mixed with the oil; probably a large amount of this carbon was present in colloidal form. It is a well-known fact that black waste oil from internal-combustion engines of all kinds cannot be freed from its carbon content by ordinary filtration and that gravity separation in settling tanks may take months to accomplish and is rarely completely satisfactory.

The normal graphite content of 0.35 per cent in an oil blended with colloidal graphite, if separated out in an engine, would be considerably less than the 3 per cent of free carbon referred to above, but, its nature being different, only practical experience can determine the actual risk incurred, if any, by the use of such "impure" oils as will cause precipitation of the graphite.

Emulsifying Effect of Water.—A quantity of diluted oildag was mixed with an equal amount of distilled water and shaken in a reciprocating bottle-shaking machine for 5 min. at room temperature. All of the colloidal graphite emulsified with the water and formed a tenacious sludge which on standing separated out between the clear oil at the top and the clear water at the bottom. It would appear, therefore, that colloidal lubricants should not be recommended for use in circulating-oil systems, when water is likely to enter the system, as is invariably the case with steam turbines; enclosed-type, force-feed lubricated steam engines; and the like.

In many enclosed-type internal-combustion engines (automobile engines, gas engines, etc.) there is no great likelihood of water mixing with the oil in service, and no objection can be raised to the use of colloidal lubricants from this point of view.

When it is desired to apply colloidal lubricants temporarily to certain bearings, there is no objection to mixing them with the lubricant in use, independent of the character of the oil, because

the mixture is immediately introduced, and there is no time for the colloid to separate out and cause trouble.

If mixtures of "impure" oil and colloidal lubricants are used continuously for a period by one of the many comparatively slow-feed oiling arrangements (bottle oiler, siphon oiler, drop-feed oiler, pad oiler, etc.), the colloid will flocculate and accumulate, the flow of oil not being sufficient to wash it away. As a result, narrow oil passages are choked, the supply of lubricant ceases, and trouble may easily occur.

Summary.—Finely pulverized solid lubricants cannot be automatically used mixed with oil unless they are kept continuously mixed by a special stirring mechanism or by the motion of the parts to be lubricated.

With colloidal lubricants, there is no difficulty in obtaining a perfect mixture, but it is imperative that only very pure oils be used for making the mixture, unless the conditions of service are such that flocculation of the colloid is not likely to lead to difficulties or trouble of a serious character.

OBSERVATIONS ON RESULTS OBTAINED BY THE USE OF SOLID LUBRICANTS

Bearings.—Numerous experiences testify to the value of solid lubricants and of graphite in particular for use in bearings.

One British railway reports that good results have been obtained by using either colloidal graphite or flake graphite mixed with their ordinary locomotive-engine oil. The graphite is not used for regular running (the compounded locomotive-engine oil would cause flocculation of colloidal graphite, and flake graphite cannot be suspended in the oil) but only as a temporary remedy, whenever important bearings are inclined to heat.

Several works report that by continuous use of colloidal graphite mixed with pure mineral oils they have obtained excellent results on heavy-duty bearings (heavy pumping engines, etc.) which previously gave trouble, even when using oils heavily compounded with fixed oil. The bearings ran not only cooler but also with an appreciable reduction in consumption of oil and without flocculation of the graphite.

Where no care has been taken to provide specially pure mineral oils, flocculation has occurred, and choking of oil channels, etc., has resulted.

Some bearings of high-speed fans, which were troublesome with oil alone, ran reasonably cool when using the same oil mixed with colloidal graphite.

A maker of dictating machines found that customers did not trouble to oil the motors; he tried oildag and found that, even when the motors received no oil for several months after the initial application of oildag, no scoring occurred, owing to the graphitized surfaces produced in the bearings.

One maker of jaw crushers lubricated the Pitman bearing by a continuous flow of water mixed with some Hudson's-soap extract and bicarbonate of soda. The Pitman always groaned for about 15 to 20 min. after starting up; after aquadag was used mixed with the water, the groaning entirely ceased.

Saving in power has been reported by several firms resulting from the admixture of colloidal graphite with the oil in use.

As the chief object in providing lubrication for ball and roller bearings is to maintain the highly polished hard surfaces in good condition, and little lubricating properties are required, it would appear inadvisable to use powdered or flaky solid lubricants for this purpose, as they would probably not improve the surface of the balls, rollers, or races; only colloidal lubricants seem to have a chance of success for such bearings. The only ball and roller bearings in which the nature of the lubricant has an influence on the friction are those in which pure rolling does not take place *i.e.*, in three- or four-point contact ball bearings and in roller bearings that develop end thrust; here some rubbing takes place under extreme pressures, and, if the surfaces are impregnated with an exceedingly fine solid lubricant, they are likely to operate with less wear and friction.

Some large lifts have vibrator wheels about 5 ft. in diameter, which travel along a smooth shaft of 8 to 9½ in. diameter. These wheels are bushed with cast iron and require careful and reliable lubrication. It has been found that by replacing ordinary lubricating grease with a grease containing artificial amorphous graphite the number of scored shafts and the amount of wear were materially reduced.

The lubrication of worm and worm-wheel reduction gears is always difficult; the pressure between the teeth is very great; even with an abundant supply of oil, the friction consists of a certain amount of solid friction in addition to fluid friction. It

is therefore to be anticipated that the use of graphite in connection with the gear oil would prove beneficial, and the results of experiments carried out at the National Physical Laboratory Teddington, England, with oildag and flake graphite on Lanchester's worm-gear testing machine show this to be the case. These experiments show that the addition of oildag to a mineral oil of relatively low oiliness improves the gear efficiency, so that the results are equal to those obtained by animal or vegetable oils.

Fine flake graphite (Foliac No. 100) also improved the efficiency with most of the mineral oils tested, and where an improvement was recorded it was greater than with oildag. The results appear, however, to be less consistent, and there was distinct evidence of greater wear than with oildag.

When the temperature of the oil is increased, a critical point is reached above which the gear efficiency rapidly decreases. The effect of adding oildag or flake graphite was in every case to raise the critical temperature about 18°C. so that an increased margin of safety in operation was thus obtained; this happened even if the addition of solid lubricant did not increase the gear efficiency at lower temperatures.

Steam Cylinders and Valves.—In many steam plants great economies could be effected if the exhaust steam could be utilized for heating or drying purposes, for washing or cooking, or if the condensed steam could be used as hot feed water. One reason why this is not done more often is the presence of cylinder oil in the exhaust steam. The oil can be entirely eliminated from the condensed steam by electrical or chemical means but not from the exhaust steam itself before condensation, although good oil separators may take out as much as 99 per cent if the cylinder oil is pure mineral in character, *i.e.*, not compounded with fatty oil, such as tallow oil.

The use of aqueous colloidal lubricants is probably limited to engines employing saturated steam and engines of small power; it must be kept in mind that if it were not for the water film produced by steam condensation in the cylinder, the friction would be very high indeed. In engines employing superheated steam, there is little or no condensation in the cylinders, and it becomes necessary to provide a lubricating film in order to avoid excessive friction and wear.

Many experiments have been made with graphite and oil for the internal lubrication of steam engines employing superheated steam. Pure, fine flake graphite may be used, or colloidal graphite may be mixed with the cylinder oil, which should preferably be a pure mineral oil, not compounded with fatty oil, as is the case with most good-quality steam-cylinder oils. The results of graphite employed in this way have in many cases been very satisfactory; appreciable reductions in consumption of oil have been recorded, also less wear of internal moving parts. Alongside these results there are also a great many failures, although no failures have been reported with colloidal graphite. The failures with flake graphite have been due to excessive and injudicious use of the graphite or to the use of coarse or impure graphite or to breakdown of the complicated lubricators required to keep the graphite-oil mixture well stirred.

Under superheat conditions the surfaces are more difficult to lubricate than with saturated steam, and the necessity for not overfeeding with graphite will be readily understood. Excess graphite accumulates behind the piston rings and in the metallic packing and will, in time, make the rings inflexible in their grooves, resulting in scoring of the surfaces, leakage of steam past pistons and piston rods, etc. Great care must be exercised in the use of flake graphite for superheated steam conditions, and only the purest graphite must be used, in order to avoid excessive wear of pistons, piston rings, cylinders, piston rods, metallic packings, etc.

Graphite has been used by many marine engineers for lubricating large, unbalanced D-type slide valves. Cast iron, being more or less porous, is a material particularly likely to benefit from the use of graphite: when the pores are filled and a graphite coating is produced it will be found that an exceedingly small amount of graphite is required to maintain the surfaces in good condition. Impregnation of such surfaces with graphite reduces the tendency to abrasion and makes it easier for the cylinder oil to maintain efficient lubrication.

When a mixture of flake graphite and cylinder oil is used for the internal lubrication of steam engines, the graphite will in time find its way out with the exhaust steam; it is easily separated from the steam and deposited in the oil separator or hot well.

Flake graphite will adhere to the baffles in the separator, and accumulations should be removed at suitable intervals.

In all cases where the use of graphite has brought about a reduction in consumption of steam-cylinder oil, it has also reduced the quantity of oil reaching the boilers and therefore reduced the possibility of boiler troubles from this source.

Internal-combustion Engines.—The use of solid lubricants for the internal lubrication of internal-combustion engines has been the subject of much controversy, and various opinions have been expressed regarding such features as preignition, carbon formation, sooting of spark plugs, ease of starting, oil consumption, and reduction in friction.

Preignition may be due to accumulation of carbon deposits, but the cause of preignition appears to be not so much the carbon itself as the earthy and other impurities (road dust, lime, iron oxides, etc.) which may be present in the deposit. Artificial graphite whether in the amorphous or colloidal form seems here to possess advantages over most natural graphite, as the presence of minute earthy impurities is more easily avoided in artificial graphite. As compared with the use of oil alone, the tendency to preignition may be said to be increased, more or less, according to the purity of the graphite.

Carbon Formation and Sooting of Plugs.—Contradictory reports are received with reference to this point. In small engines, such as motorcycles, no difficulty is experienced; some records even report less sooting of plugs when using colloidal graphite, but that may perhaps be explained by a more economical use of the oil when using graphite.

The colloidal graphite is not consumed in the combustion space but, in the form of an exceedingly fine dust, spreads and adheres to the walls of the combustion chamber and the sparking plugs. The greater the consumption of oil the more graphite is deposited.

The formation of oil carbon depends on the amount of oil burnt inside the cylinders and on the nature of the oil; some oils produce more carbon than others, but the amount of oil carbon produced will normally never exceed 0.02 per cent of the oil used. Although hydrocarbon oils contain over 80 per cent of carbon, most of the oil is vaporized and decomposed into other hydrocarbons, with the result that the actual amount

of oil carbon formed is a very small percentage of the amount of oil consumed.

When mixing colloidal graphite with oil to give a graphite content of, say, 0.35 per cent in the mixture, it must be remembered that this graphite is not consumed and that unless a large percentage of the graphite is swept out by the exhaust gases, or a very large reduction in oil consumption takes place, the formation of carbon may easily be greater than with oil alone.

Ease of Starting.—Opinions appear to be unanimous that when graphite is used, engines (motorcycles, automobile engines, gas engines, etc.) start more easily and with greater freedom. The following contribution to *Motor Cycling* may be quoted:

> I found when using oildag that carbonization was markedly reduced, even under the very heavy lubrication that I give my engine as a rule. Engine "freeness" (allowing for the inherent freeness of the engine) is marked. The pressure of either valve spring acting on the engine via the tappet and cam was sufficient to rotate the back wheel of my T. T. single to the point of rest of the valve spring, so you can imagine there was not much friction in that engine. The cylinder walls took on a very high mirror-like polish. I found no concretion behind the piston rings, and what carbon deposit there was in the cylinder head and on the piston top was soft and easily removed. The effect of the graphite on the valve stems, particularly such a hot-working stem as that of the exhaust valve, was wonderful. The graphite was able to resist the heat and gave the valve stems a similar "mirror" surface to that of the cylinder. I further used it as a general lubricant for the cycle details. Carbureter slides polished and lubricated with oildag worked very smoothly and with a minimum of air leakages. It was also useful as a dressing for screw threads liable to bind or stick and on valve caps and plug threads; it made a good but easily broken joint.

Oil Consumption.—Saving in oil consumption, made possible by the use of graphite, is due to the smoother surfaces of pistons and cylinders and the more uniform and slightly smaller clearance space between them. Better compressions are also obtained due to less leakage past the piston. When the initial oil consumption is large, as with aircraft engines, the saving is apt to be overlooked; but with small engines and where adjustable mechanical lubricators are employed, the saving obtained may be quite considerable.

Reduction in Friction.—Speaking generally, half the friction in an internal-combustion engine is piston friction; the lubricating

oil film is probably never complete, and so a certain amount of metallic contact (solid friction) invariably takes place. Porous cast-iron surfaces are easily filled and coated by graphite, and an appreciable reduction in friction may be anticipated when the necessary care is taken in the judicious use of the right kind of graphite.

In the United States, colloidal graphite appears to be extensively used for the initial "running in" of automobile engines; it is said to save considerable time in producing a good surface and gives the engines a good internal skin before leaving the builders' works.

Ropes, Chains, and Gears.—Various greases are usually employed for the lubrication and preservation of ropes, chains, and gears, and, as already mentioned, the admixture of a small amount of good-quality finely divided graphite is beneficial. Messrs. Hans Renold, Ltd., London, find that with intermittently lubricated chain drives, graphite grease containing artificial amorphous graphite is very suitable. When the chain has been soaked in the hot liquid grease it will work without further lubrication for a long period—sometimes for several months—whereas with thin oil in use it must be applied at least once a week, and then the results are not always satisfactory, a reddish deposit (rust) being found in the bearings of the chain. With graphite grease this deposit does not form. The same firm also reports that the clutch band in their power clutches, when lubricated by graphite grease, requires no attention for long periods.

When chains or gears are enclosed in an oiltight casing, the use of an oil bath is preferable to grease; in this case, the admixture of a small amount of finely pulverized graphite or colloidal graphite is also beneficial.

Metal Cutting and Wiredrawing.—Colloidal solid lubricants—such as aquadag—have been used as coolants for cutting purposes. Experiments seem to indicate that colloidal solid lubricants are not satisfactory when used for this purpose by themselves. They do not flow to the tool point if it is greasy, and the tool point therefore wears; when they are mixed with ordinary cutting emulsions or soap and water, good results have been obtained, but the high first cost of colloidal lubricants militates against their use for cutting purposes; the staining effect of the graphite on the hands of the operators is also objectionable.

In metal wiredrawing operations semisolid lubricants are used, such as mixtures of olive soap and powdered talc. There appears to be no reason why a vegetable soap mixed with a suitable amount of finely powdered graphite should not be capable of rendering good service.

Aquadag is used in wiredrawing the metal filaments (Dempsters Patent 17722, 1911) used in electric lamps; the dies require a certain amount of lubrication to produce a satisfactory thread, and aquadag is apparently the only nonoily lubricant that has given satisfaction for this purpose.

CHAPTER IX

RING-OILING BEARINGS

Ring oiling is employed largely on modern high-speed shafting bearings, practically all electric motors and electric generators, also small steam turbines. Main bearings in most gas engines, Diesel engines, and horizontal oil engines, as well as many steam engines, employ the ring-oiling system for the crankshaft bearings.

The advantages of ring oiling over the drop-oiling system are many:

1. Better and more uniform lubrication.
2. Greater oil economy.
3. Greater factor of safety in operation.
4. Greater cleanliness.
5. Less attention required.

Ring oiling is used for small as well as large bearings but not for the very smallest, say below 2 in., running at high speeds, as the rings frequently fail to operate, and it is difficult to prevent frothing and waste of oil.

The bearing housing (Figs. 31*A* and 31*B*) forms an oil reservoir in which the oil is maintained at a certain level, preferably indicated by an oil gauge, which may also serve for the introduction of the oil.

On the shaft are usually suspended one or two rings or chains dipping into the oil; when revolving, the rings carry oil to the top of the shaft, from which it runs into the oil-distributing groove on the "on side" of the journal and spreads over the bearing surfaces. This groove extends to within ½ in. of the bearing ends and is well chamfered to facilitate the oil's wedging its way into the bearing. If the motor is reversible, two oil-distributing grooves are obviously needed, one on each side. No other oil grooves should ordinarily be made, as the high surface speed assists the oil materially in getting in between the rubbing surfaces.

When the surface speed is low, and the bearing pressure high, oil grooves may be advantageous, as explained on page 121.

When speeds are low, or the oil becomes thick (cold mornings), oil rings may not start readily. Figure 29 illustrates an oil ring with notches filed on the inside, which are said to assist the ring in starting, owing to the greater friction between the ring and the shaft.

For low-speed bearings, oil rings are sometimes replaced by chains, which touch the shaft over a long arc and are therefore kept in motion with greater certainty than plain rings. At high speeds, chains have the disadvantage that the links churn the oil, which leads to foaming and leakage of oil from the bearings.

When the speeds are exceptionally low, say a few revolutions per minute, neither rings nor chains are satisfactory, and oil

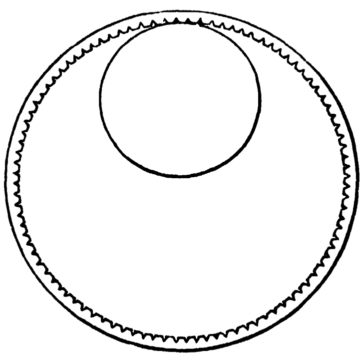


FIG. 29.—Notched oil ring.

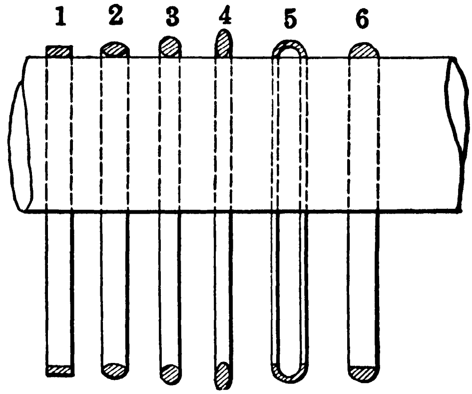


FIG. 30.—Various types of oil rings.

rings or collars fixed on the shaft are employed, whence the oil is removed by stationary scrapers in the upper part of the bearing, guiding the oil afterward into the oil-distributing groove. Such bearings are employed on the drying cylinders of papermaking machines and other slow-speed machinery but are also occasionally used for moderate-speed machines. Oil rings are usually made twice the diameter of the journal, the oil level being at a distance below the shaft about half its diameter.

One oil ring will suffice for bearings up to 8 in. in length. Two oil rings are needed for bearings from 8 to 16 in. in length; and three for larger bearings.

As to the shapes of oil rings, there are a great many; some are indicated in Fig. 30. They should preferably be made undivided. When made in two halves and jointed, slight wear may cause them to operate irregularly or even refuse to revolve. Unevenness at the joint at high speed leads to foaming of the oil and oil

spray. Unevenness or roughness on the two sides of the oil ring will have similar effects. Rings that are slightly oval, due to lack of care during manufacture, will obviously be inclined to stick.

In large bearings, cooling of the oil by introducing a cold-water coil in the reservoir may be found desirable or even necessary under severe conditions (see "Turbines").

Difficulties sometimes occurring with ring oiling are

1. Foaming and spraying.
2. Leakage, endways or sideways.

Foaming and Spraying.—Troubles of this kind may be due to too high revolving speed of the oil rings or to too low an oil

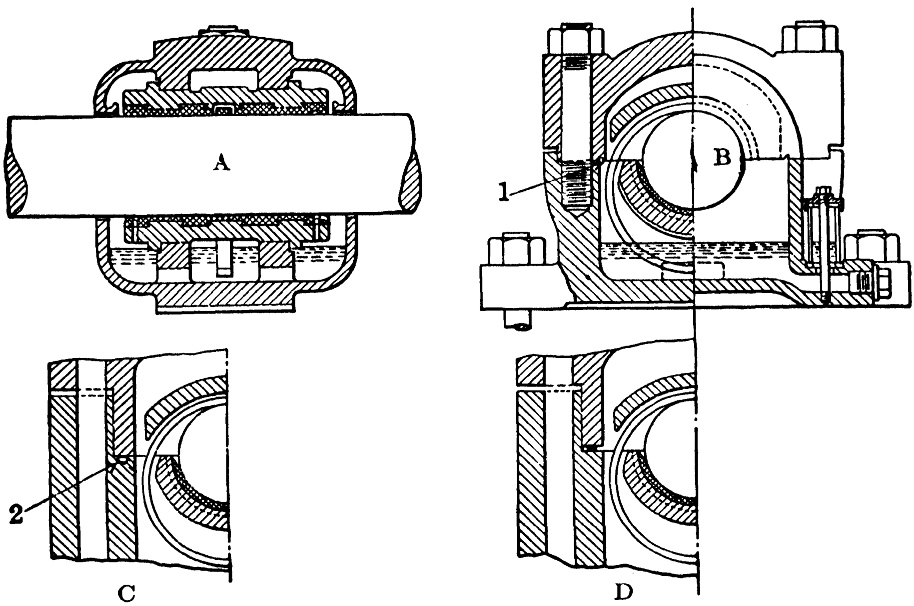


FIG. 31.—Ring-oiling bearing.

level (which brings about quick speed of the rings owing to the smaller resistance offered to the movement of the rings through the oil). The oil is violently thrown away from the rings, forming oil spray, oil foam being formed by the rings' drawing air into the oil where they enter the surface of the oil. Excessive foaming and oil spray always mean waste of oil, as the finest oil spray finds its way through the bearing ends or covers. Such loss of oil may become dangerous by lowering the oil level so much that the bearings will receive too little oil.

Leakage through the side of the bearing between the top and bottom parts can be overcome by inserting a thin leaden wire which, when the bearing is put together, is squeezed flat and forms a seal (Fig. 31*D*). The lip (1, Fig. 31*B*) is intended to prevent such oil leakage; also the longitudinal drainage groove (2, Fig. 31*C*), which is sometimes found in large bearings, draining the oil back to the reservoir at its two ends.

The proper remedy is, however, to have a type of oil ring suitable for the size and speed of the shaft. The speed of the oil rings is governed by the *propelling force* caused by oil adhesion between the ring and the journal where they touch at the top and the *retarding force* caused by the opposition to movement created by the speed of the ring through the oil in the well. It will be recognized that oil rings 2, 3, 4, and 5 will give lower ring speeds (more slip) than oil ring 1, whereas No. 6 will usually give greater speed than No. 1 owing to less surface in contact with the oil—therefore less resistance with the same propelling force. By finding out from practical experiments which type of ring gives a suitable speed and oil feed, the majority of troubles with ring-oiling bearings may be overcome.

It is particularly important to study this point when outside the bearing there is a pulley, which in revolving creates a suction, tending to increase loss of oil from the bearing. The oil when leaving the ends of the bearing drops back into the oil reservoir and is thus kept in constant circulation. If the bearing is well designed, there will be very little oil waste by leakage or by oil's creeping along the shaft. Sometimes the oil creeps spirally along the shaft and is thrown away where it is least desired, creating unsightly oily floors or spoiling fabrics, *e.g.*, cloth looms. The remedy may lie in lowering the oil level or altering the type of oil ring, but the root of the trouble may be wrong shaping of the bearing surfaces. Figure 31*A* shows how the edge must be rounded off, which helps to prevent oil creeping, whereas a sharp edge does not hinder the oil in passing along the shaft.

An excellent arrangement is to have a circumferential oil groove with *sharp edges*, as shown in Fig. 31*A*, with a drainage hole at the bottom; in addition, a longitudinal drainage groove also with sharp edges will assist in preventing excess oil's reaching the bearing ends, as shown at the right-hand side of Fig. 31*A*. Other methods rely upon oil throwers formed on the shaft and suitable

shapes of bearing housings at the end to receive the oil and convey it to the oil reservoir.

Figure 32 shows the simplest form of oil throwers. This construction, with a drainage passage from left to right through a center wall, in one case caused the oil to overflow from the left-hand chamber, owing to the passage's being almost choked with dirt.

Bearing Clearance.—A clearance of 0.002 + 0.001 in. per inch of shaft diameter represents normal practice and will give satisfaction as long as the deflection of the shaft due to an overhang-

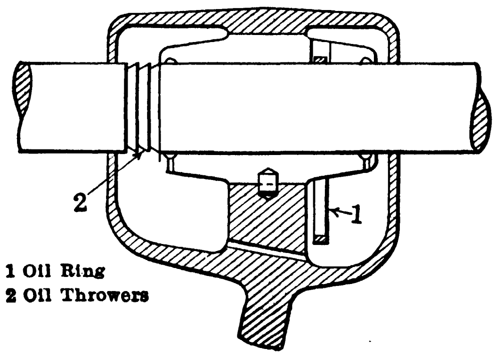


FIG. 32.—Simple oil thrower.

ing pulley, heavy flywheel, or rotor close to the bearing does not exceed this clearance.

To take care of such shaft deflection, medium- and large-size bearings are frequently self-aligning, being made with spherically seated housings.

Care of Ring-oiling Bearings.—When ring-oiling bearings are well designed, with large oil wells and employing good-quality oils, they will operate for long periods without undue attention or loss of oil. During the first few weeks of service the oil wells of new bearings should be emptied and recharged with fresh oil every few days in order to remove any molder's sand or grit which may still be present in the bearing. Once the bearing is clean, and a good skin formed, it will be sufficient to empty the wells every 3 months and recharge them with fresh oil or a mixture of filtered and fresh oil. When the bearings are situated in dusty surroundings, more frequent changes of the oil may be desirable, as dust will find its way into it, notwithstanding precautions in the way of wooden or felt rings fitted in the bearing ends; of course, such rings do reduce the amount of dust that

enters. Where chemical fumes are present in the air, which have a destructive effect on the oil, it must also be changed frequently.

When good-quality mineral oil is used, it can be filtered and used over and over again, so that the oil consumption per year is usually very small. When oils with a mineral base but compounded with animal or vegetable oils are employed, they will develop gumminess in the bearings and necessitate cleaning. Such cleaning is unnecessary when straight mineral oils are employed; cases have been known where good-quality oils have been in use for years without any real necessity for cleaning the bearings or the oil wells.

When a change is made from a compounded oil to a mineral oil, the latter will loosen the accumulations formed by the old oil. In such cases it is advisable to renew the charge after a few weeks' run; the oil when withdrawn will be very dark in color, owing to the deposits and perhaps very slight initial wear due to the bearing surfaces' adapting themselves to the new oil, but a fresh charge ought to work clean, if the new oil is of the right quality and the bearing has been completely cleansed.

CHAPTER X

ELECTRIC GENERATORS AND MOTORS

Satisfactory bearing lubrication, *i.e.*, cool running and inappreciable wear, is very important. If wear takes place, the rotor is lowered, and the magnets will then exert a pull on the rotor in a downward direction, which further increases the bearing pressure and accordingly the wear. Most bearings therefore operate with bearing pressures of 50 to 100 lb. per square inch and are oil flooded.

Ring-oiling bearings are most frequently used.

Ball bearings are also coming much into use, particularly as smaller size horizontal bearings and as vertical bearings and in dusty surroundings, in which case grease is often used in preference to oil.

When a new generator or motor exhibits a tendency to develop heat in one bearing, the bearing should, of course, be examined. If it be found in good condition, the cause of the heating may be found in the thrust of the armature shaft against the bearing, which may result from one of two conditions. First, the machine may not be level, and the armature shaft may "dip." Second, the magnetic centers of the pole pieces and armature may not be in line; *i.e.*, the pole pieces may not be exactly centered in their relation to the magnetic center of the armature axially, and, as the tendency of the armature is to run to the true magnetic center, it will automatically tend to move toward that position, which may cause the shaft collar to rub against the bearing at one end and cause heating.

The unbalanced magnetic condition may have been caused by forcing the armature not quite far enough or a trifle too far on to the shaft in the factory. Some motors are furnished with slots in the field-magnet yoke through which the field-magnet cores are bolted to the yoke, and the cores may be shifted a trifle to the right or left to compensate for any slight axial unbalancing of the magnetic center as compared with that of the armature.

Moving the magnet cores $\frac{1}{16}$ in. will, as a rule, be sufficient to give relief. If the field-magnet yoke is not slotted, a light cut may be taken off the shoulder of the shaft, at the end that rubs against the bearing, in order to obtain the necessary clearance.

Oil throwing from the bearings into the generator or motor is a troublesome disease, often very difficult to cure. Several remedies have been mentioned under ring-oiling bearings, but they are not always effective with those types of electric dynamos which create a draught. When the generator is enclosed, and the venti-

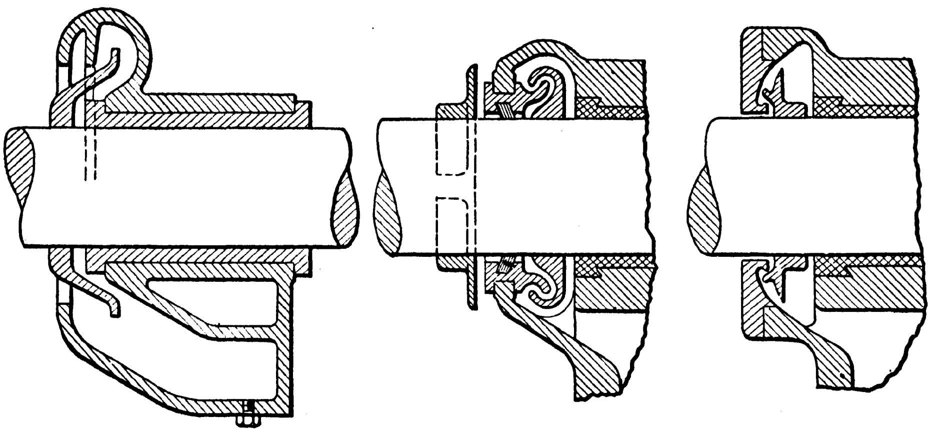


FIG. 33. FIG. 34. FIG. 35.
FIGS. 33–35.—Oil throwers.

lation led in from below, this danger does not exist or, at any rate, exists to only a slight extent; but when the generator is not enclosed, the oil finds its way into the ventilating ducts, tending to choke them with dirt and dust, which adhere to the oil. The oil also gets on to the commutator or slip rings and causes sparking.

In Figs. 33, 34, and 35 are illustrated some more elaborate methods adopted to prevent oil throwing. Figure 34 shows a series of thin copper plates, which only lightly touch the shaft and thus create an effective labyrinth seal; but they are inclined to cause wear of the shaft, small gritty particles embedding themselves in the soft copper surfaces. Certain information on this subject is also given under "Turbines."

It is said, and it sounds quite feasible, that compounded oils do more damage when getting on to the windings than straight mineral oils, as they absorb moisture and thus reduce the insula-

tion resistance of the armature more than straight mineral oils, which are not hygroscopic.

Commutator Lubrication.—Lamp oil (kerosene) used very sparingly is probably the best oil to keep the commutators clean and well lubricated. It also softens the mica and thus causes it to wear down so that it does not stand out beyond the bars.

DYNAMO OILS

Three grades of dynamo oils will take care of most requirements; they are all pure mineral oils, *viz.*, bearing oils 2, 4, and 5 (see page 135). The oil is somewhat exposed to oxidation during its continuous circulation in the bearings, but as long as the bearing temperatures do not exceed, say, 120°F., there is no need to have specially prepared dynamo oils; where the oil temperatures exceed 120°F., circulation oils of the corresponding viscosities should be preferred to ordinary bearing oils.

A rough guide for selecting the correct viscosity of dynamo oil is given in the following chart:

Lubrication Chart
For Electric Generators and Motors

Bearing Oil 2* *or Circulation Oil* 1.†—For small electric generators or motors up to 50 hp. and up to 100 hp. when there is no excessive belt pull on the shaft close to the bearing.

Bearing Oil 4 *or Circulation Oil* 2.—For larger electric generators and motors under normal operating conditions and for motors below 100 hp. with excessive bearing pressures.

Bearing Oil 5 *or Circulation Oil* 3.—For generators or motors above 100 hp. operating with excessive bearing pressures.

Ball-bearing grease is employed only for smaller motors, operating in dusty surroundings or in hot and moist climates.

* See p. 57.
† See p. 243.

CHAPTER XI

PLAIN THRUST BEARINGS

Horizontal thrust bearings are designed to take up axial thrusts of revolving parts, *e.g.*, in horizontal centrifugal pumps or turbines or the propeller shafts in marine steam engines.

Vertical thrust bearings are employed to carry the weight of revolving parts, *e.g.*, in vertical water turbines or centrifugal pumps and vertical electric generators or motors.

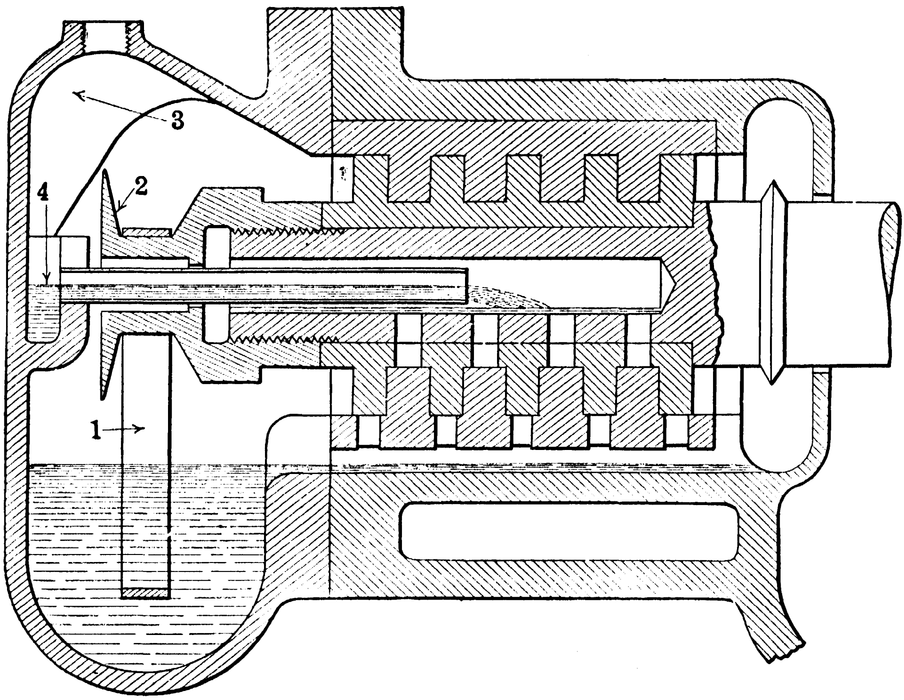


FIG. 36.—Ring-oiled thrust bearing.

Collars on the shaft transmit the pressure to stationary collars, various means being employed to introduce an oil film between the rubbing surfaces, as described under "Turbines" and "Marine Steam Engines." Figure 36 illustrates a method of oiling the thrust bearing in high-speed pumps. By means of an oil ring (1) the oil is thrown off the collar (2) against the oil

catcher (3), whence it runs into the oil cup (4) and reaches the hollow shaft, finally returning to the oil well. The lower part of the bearing is water cooled. Figure 37 illustrates an unsatisfactory method, as the large oil disk (2) causes foaming and creates heat.

Figure 38 illustrates an ingenious method of providing oil circulation in a vertical thrust bearing supporting a shaft revolv-

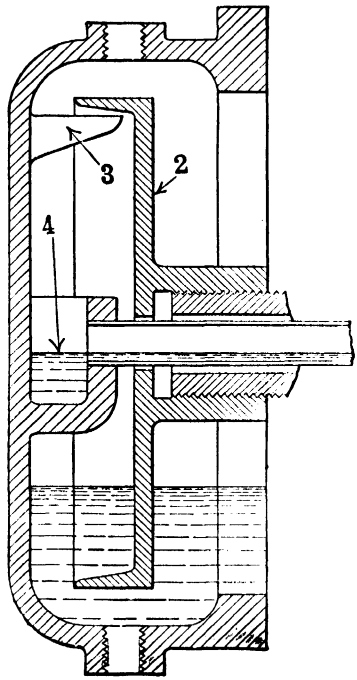


Fig. 37.

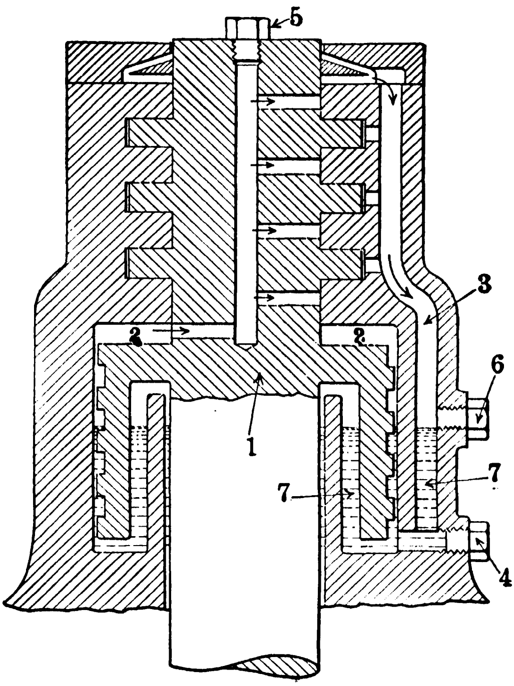


Fig. 38.—Vertical thrust bearing automatic oil circulation.

ing at 1,500 r.p.m. upon which is fitted an electric motor driving a centrifugal deep-well pump at the lower end of the shaft.

The shallow spiral grooves on the part (1) lift the oil into the oil chamber (2); the oil pressure created here drives the oil through the oil drillings in the shaft; the oil after doing its work reaches the oil-return channel (3) and the oil well (7) which is so arranged that the oil cannot overflow down the shaft. The drain plug (4) is removed when it is desired to empty the bearing, and, when the bearing is being filled through the filling plug (5), the overflow plug (6) is removed so as to ensure a correct oil level.

When thrust bearings have only one collar or one rubbing surface, they are called step bearings or pivot bearings.

Figure 39 illustrates the simplest form of step bearing; the revolving shaft rests on three washers; the top washer may be arranged to revolve always with the shaft, so as to save wear of the shaft itself. With low bearing pressure only one washer is needed; the higher the pressure the more washers are required. When one washer begins to heat and seize, it stops revolving, and one of the cooler washers starts to revolve, so that they divide the work between them, only one washer acting at a time.

The washers should always have shallow radial oil grooves cut in their rubbing faces, the grooves stopping slightly short of the edges; and the trailing edges of the grooves should be well rounded to facilitate the entrance of oil between the surfaces.

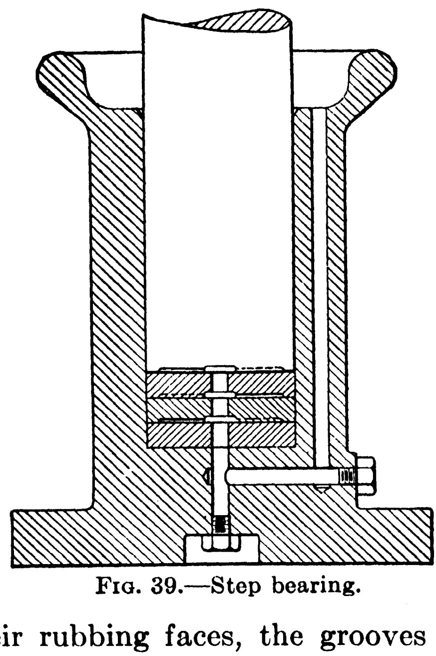


FIG. 39.—Step bearing.

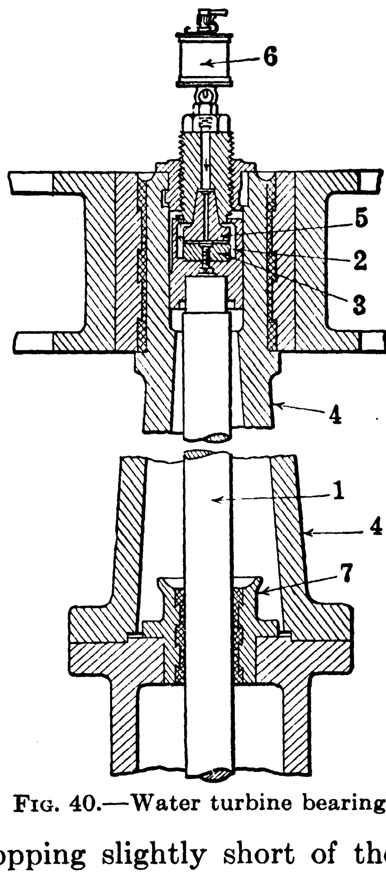


FIG. 40.—Water turbine bearing.

The oil enters the central hole; rises to the top owing to centrifugal action; and returns through the drain hole. When such bearings get uncomfortably warm, a remedy is to increase the flow of oil by means of a pump which forces the oil in under pressure; the oil returns from the top through a pipe into an oil reservoir, whence the pump draws its supply. In this way a

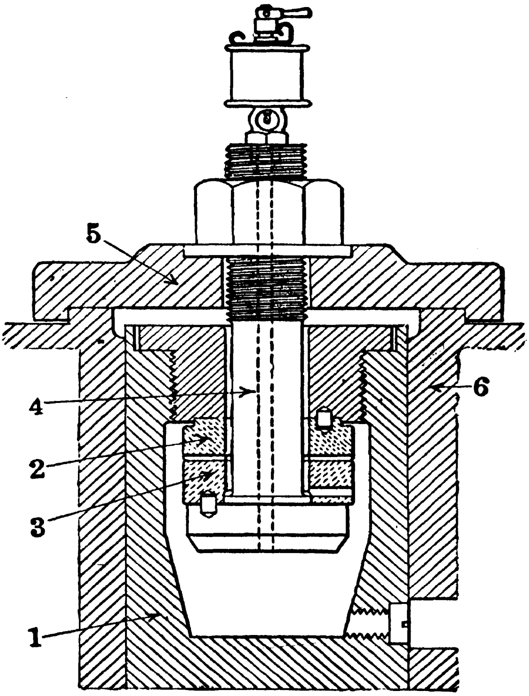


FIG. 41.

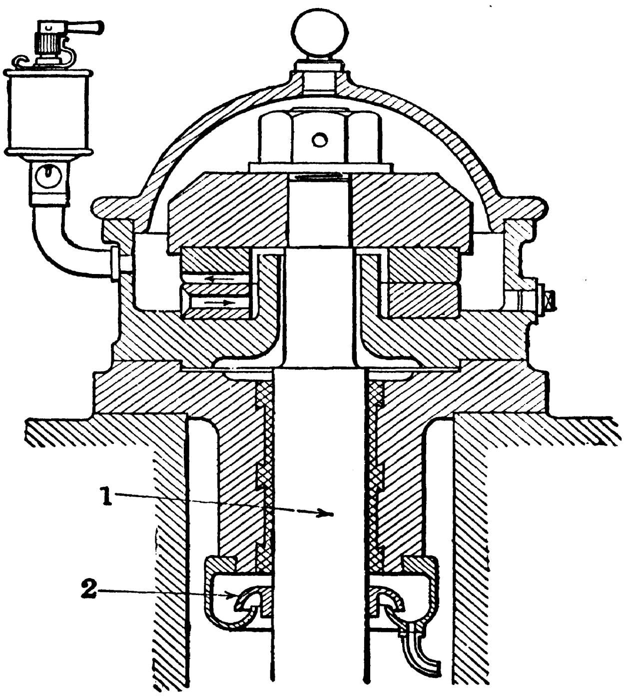


FIG. 42.

FIGS. 41–42.—Water turbine bearings.

greater radiating surface is obtained, and the bearing will run cooler.

Vertical water turbines make use of bearings as illustrated in Figs. 40, 41, and 42. In Fig. 40 the weight of the turbine is taken by a stationary vertical shaft (1) which has an oil reservoir (2) at the top with a bronze washer (3). The hollow revolving shaft (4) carries the weight of the revolving parts and transmits the pressure through the hardened-steel part (5) to the washer (3). Oil is fed through the top from a sight-feed drop oiler (6). The overflow oil runs down into the guide bearing (7), which is under water; at the lower end there is a gland packing to prevent entrance of water into the hollow shaft, but, as some water generally gets in, compounded oils, such as marine-engine oil 1 or 2 (see page 267) should be used, which will emulsify with the water and maintain efficient lubrication.

In Fig. 41 the shaft (1) and washer (2) revolve; the stationary washer (3) receives the full pressure and transmits it through the stationary shaft (4) and cover piece (5) to the casing (6). The oil circulates continuously through the oil grooves, which extend right to the edge. It will be noticed that the bearing surface in this design is very small; the bearing is very compact, so that a rich viscous oil, such as marine-engine oil 1, must be used.

In Fig. 42 the bearing surface is much bigger, also the radiating surface is greater, which gives cooler running; ordinarily, a slow oil feed from a sight-feed drop oiler suffices; but where high pressure exists and the heat developed is great, an oil-circulation system may be employed.

The oil to use in such bearings as Figs. 37, 38, and 42 may well be circulation oil 1 or 2, as the bearing pressure is low, and the revolutions are usually high, say above 100 r.p.m.

A special type of step bearing is employed in the Curtiss vertical turbines, as described on page 238.

By far the most satisfactory and reliable type of thrust bearing for heavy pressures, whether the speeds are high or low, is the Michell or Nomy single-collar thrust bearing. The collar or footstep rests upon a fixed bearing surface, which is divided into a number of segmental pads, each pivoted so that it is free to rock and take up any inclination to the moving surface that the conditions of speed, pressure, and viscosity of the oil may demand. Figure 43 shows two Michell methods of supporting the pads, *viz.*, pivot-

ing along a line and pivoting on a point, the pivoting line or point being placed a little behind the center of each pad; experience shows this to be important to give a perfect film and therefore minimum friction. As the collar (1) moves over the pad (2), a wedge-shaped oil film is established; the oil is continuously drawn in at the leading edge, where the oil film is thickest, and escapes at the trailing edge, where the oil film is exceedingly thin. Some oil also escapes along the sides of the pad, as indicated in Fig. 44, which shows the directions of oil flow. These interesting photographs are reproduced by the courtesy of W. J. Hamilton Gibson,

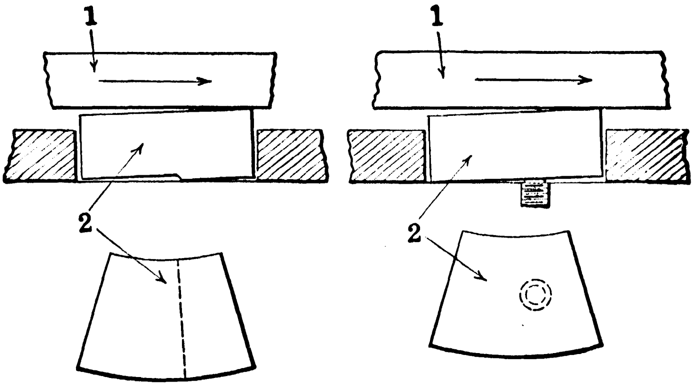


FIG. 43.—Michell thrust pads.

more details being given in his paper before the Institution of Naval Architects, London, April, 1919.

In some interesting experiments made by Brown, Beven & Co. the effect of slightly rounding the leading edge of the pads was found to be an increased carrying power and a slight shifting further aft of the center of pressure; these experiments also confirmed Michell's opinion as regards the shape of the pads, which should be approximately square to give the best results.

The pads are usually white metaled, and one might ask why go to this trouble, as there is no metallic contact? The character of the metal of the lubricated surfaces ought not to influence the results, as long as they are strong enough to stand the pressure; fine particles of grit or dirt may, however, be carried in between the surfaces with the oil; in that case the white metal will become abraded, and this is preferable to injuring the collar, which would occur were the pads made of hard material.

The oil film is very thin—sometimes less than 0.001 in.—so that the bearing surfaces must be carefully scraped, and oil grooves

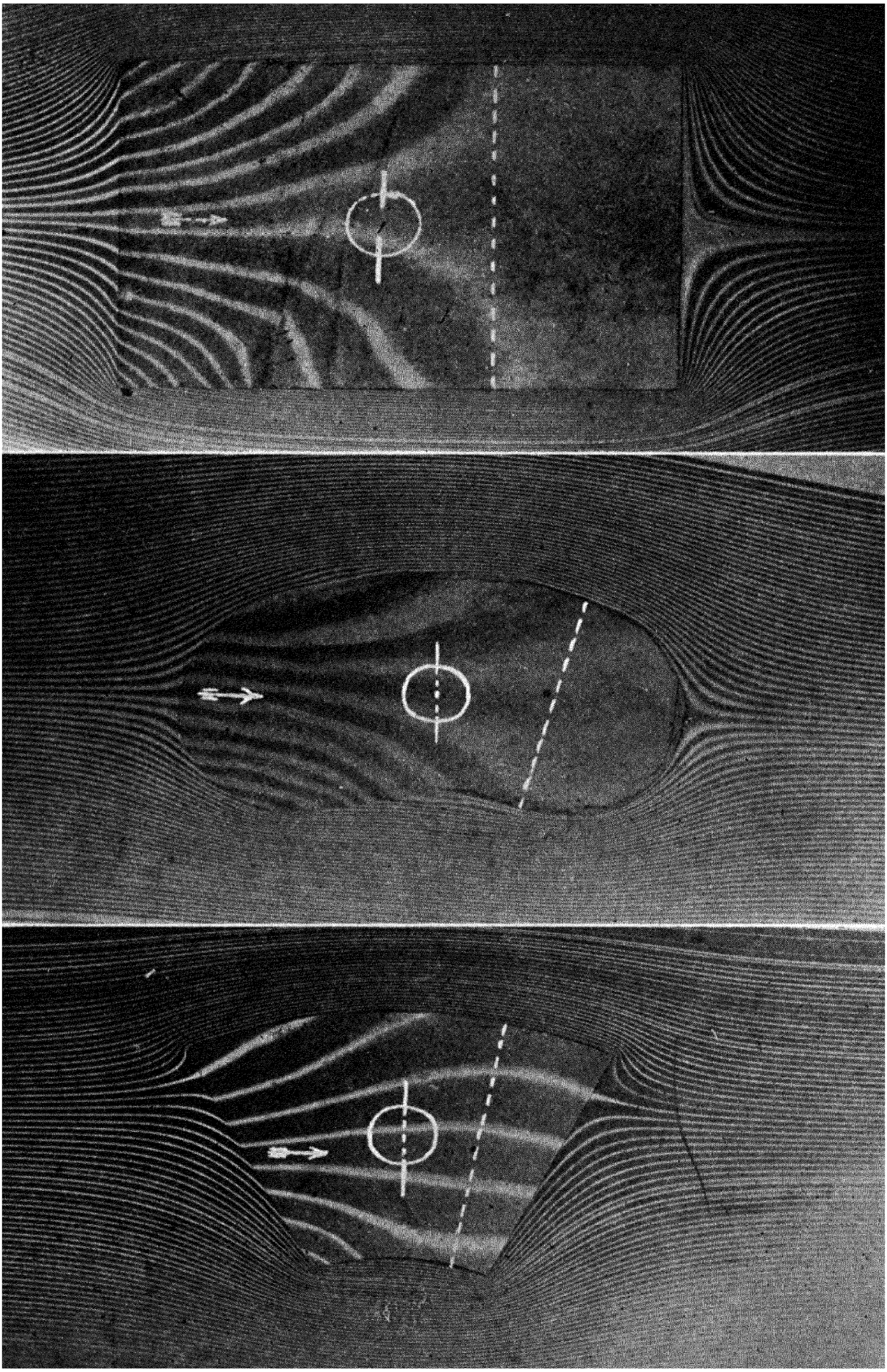


FIG. 44.

must on no account be cut, as they will allow the oil to escape and prevent proper film formation.

The heat generated in the bearing is entirely due to internal fluid friction in the oil film, there being no metallic contact; the frictional heat is therefore dependent upon the area of the thrust pads, the rubbing speed, and the viscosity of the lubricant. The makers supply particulars as to the amount of heat generated under specific conditions and the quantity of oil and cooling water required to give the best results.

The number of pads may vary but is usually six. They may be arranged in the form of an inverted horseshoe, as in the self-

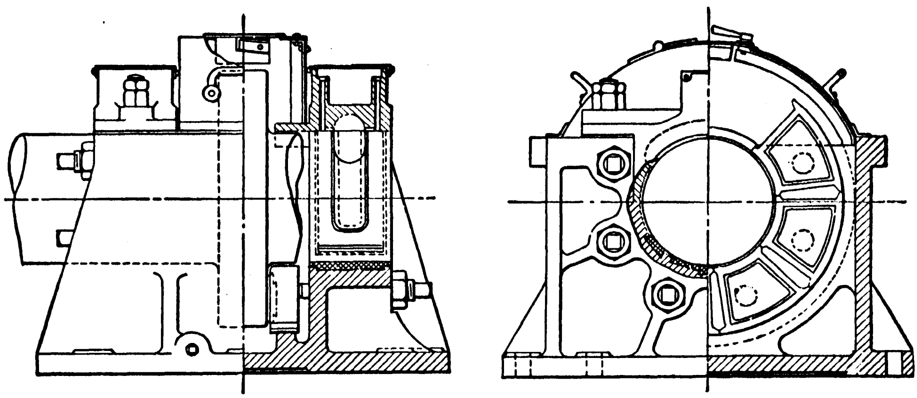


FIG. 45.—Michell marine thrust bearing.

contained marine thrust bearing (Fig. 45), suitable for both geared turbines and marine steam engines; or evenly distributed over the collar, as in the geared turbine thrust bearing (Fig. 46).

In Fig. 45 the collar bears against two inverted horseshoe-shaped surfaces (one for ahead and one for astern thrust). Each of these surfaces is subdivided into six pads pivoted on the ends of a corresponding number of screws. The shaft is supported by two ordinary journal bearings, and the well in which the collar revolves is filled about half full of oil, which lubricates the blocks; the journal bearings have upper keeps, fitted with siphon oilers, and a light sheet-iron cover forms a dust shield.

The housing consists of one main casting and is water-jacketed in large-size bearings or when the speed is high.

In Fig. 46 the shaft is carried in two journal bearings, the same as in Fig. 45, but the housing is made in halves, and the blocks instead of being independently adjusted are mounted in spherical

seats and adjust themselves automatically. This type of bearing is not self-contained, as in Fig. 45, but must be connected to an oil-circulation system, usually a branch from the main-turbine oiling system. The blocks may be either "line pivoted" on the spherical seats or "point pivoted," as shown.

For steam turbines, where the thrust bearing is combined with the main bearing at the high-pressure end, and when the thrust does not exceed 5,000 lb., a much simpler form of Michell

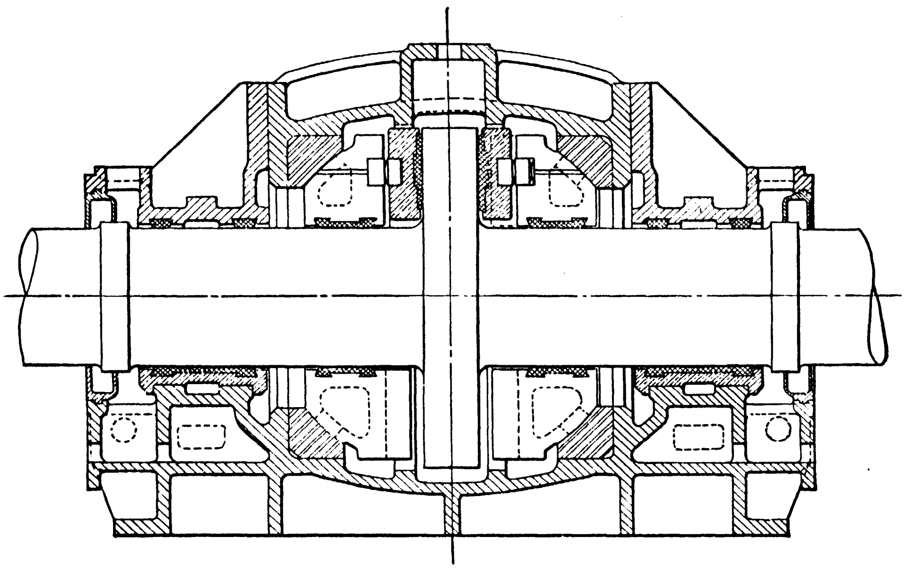


FIG. 46.—Michell turbine thrust bearing.

bearing is designed, one type having only one pivoted pad on either side of the collar. The Michell thrust bearing is also used with great success as vertical thrust bearings, required for vertical water turbines, centrifugal pumps, vertical electric generators, etc.

It will be recognized that a perfect oil film cannot be established in the ordinary form of thrust bearing in which the coefficient of friction is about 0.03, whereas in the Michell bearing it falls to 0.002 or even less. The Michell thrust bearings will safely carry a load of 400 to 500 lb. per square inch with rubbing speeds from 60 to 100 ft. per second, without danger of metallic contact. Michell thrust bearings have run with no abnormal heat, carrying a pressure of 5 tons per square inch, a pressure at which the white metal surfaces of the pads began to flow like butter, thus

showing that with perfect film formation the oil film will stand enormous pressures.

The Kingsbury thrust bearing is designed on very much the same lines as the Michell bearing. Kingsbury also divides the supporting surface in segmental pads, and the pads are made self-adjustable by rounding the supporting surface, as shown in Fig. 47. The pad (2) rocks over the support (3) and thus allows a wedge-shaped perfect oil film to form between the pad and the revolving collar (1).

The oils used for Michell thrust bearings are mineral oils of suitable viscosity. There is no need for compounded oils, as the film formation is not influenced by the oiliness of the oil. All that is required is viscosity. For slow-speed conditions, viscous oils are required, like bearing oil 4 (see page 135) or

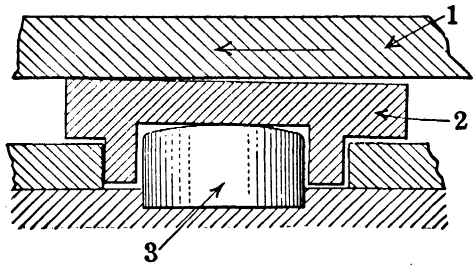


FIG. 47.—Kingsbury thrust pad.

circulation oil 3 (see page 243); for high-speed conditions, as in steam turbines, the same turbine oil is employed for the Michell thrust as for the turbine bearings. The Nomy bearing principle is somewhat similar to the Michell principle and is further explained in Chap. XIII, page 195. Nomy thrust bearings therefore offer the same advantages as Michell thrust bearings as compared with ordinary thrust bearings.

Compounded marine-engine oils may be used for steam-engine Michell or Nomy thrust bearings for the sake of simplicity, but straight mineral oils operate cleaner and should be preferred.

CHAPTER XII

BALL AND ROLLER BEARINGS

Ball and roller bearings operate on different principles from plain bearings; the *rolling contact* between the balls or rollers and the stationary or revolving surfaces (ball races, roller races) is theoretically only point contact in ball bearings, and line contact in roller bearings, whereas ordinary bearings have large surfaces in *rubbing contact* at all times. When machinery equipped with ordinary bearings is started the frictional resistance is great, several times as great as the resistance after a couple of revolutions, when the oil film has been established; whereas in ball and roller bearings the friction at starting is the same as or only very little more than the friction during operation, and is always lower than in plain bearings.

It is this great advantage that ball and roller bearings have over plain bearings which is chiefly responsible for their ever widening use, particularly in machinery that frequently starts and stops or changes its direction of rotation, such as automobiles, motorcycles, bicycles, reversible electric motors, railway turntables, etc.

Roller bearings may possibly stand rough use, vibration, and shocks better than ball bearings, but they will not carry heavier loads, as many people seem to think, and at very high speeds ball bearings are usually preferred. Professor Goodman has made a lengthy study of ball and roller bearings, and the following remarks are largely based on the information given by him in papers read before the Institution of Civil Engineers, 1911–1912, and the Institution of Automobile Engineers, in 1913.

ROLLER BEARINGS

The rollers are nearly always plain cylindrical. Most bearings have a cage, as in Fig. 48, to hold the rollers in position.

The Hyatt bearings (Fig. 49) have rollers which are helical springs, alternately of right- and left-hand pitch, and are much used for line shafting.

The Timken roller bearing (Fig. 50) has two rows of tapered rollers and is used largely for automobiles.

The pressure on the narrow line of contact between roller and shaft is great; hence, soft materials are liable to be crushed, and the wear is excessive. For high pressures the rollers, sleeve,

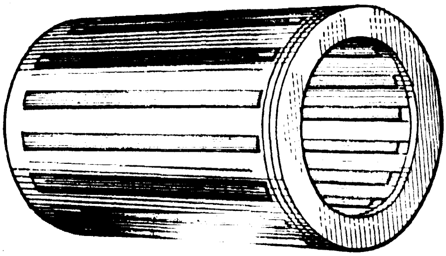


FIG. 48.—Roller-bearing cage.

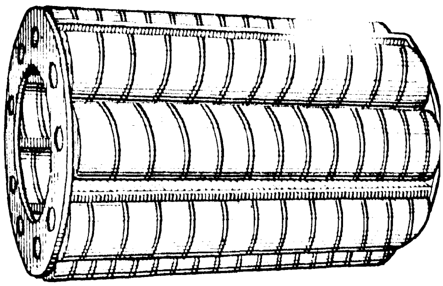


FIG. 49.—Hyatt rollers.

and casing liner should be steel hardened and ground so as to minimize the wear.

During operation the roller cage moves at approximately half the journal speed, and the rollers revolve at very high speed,

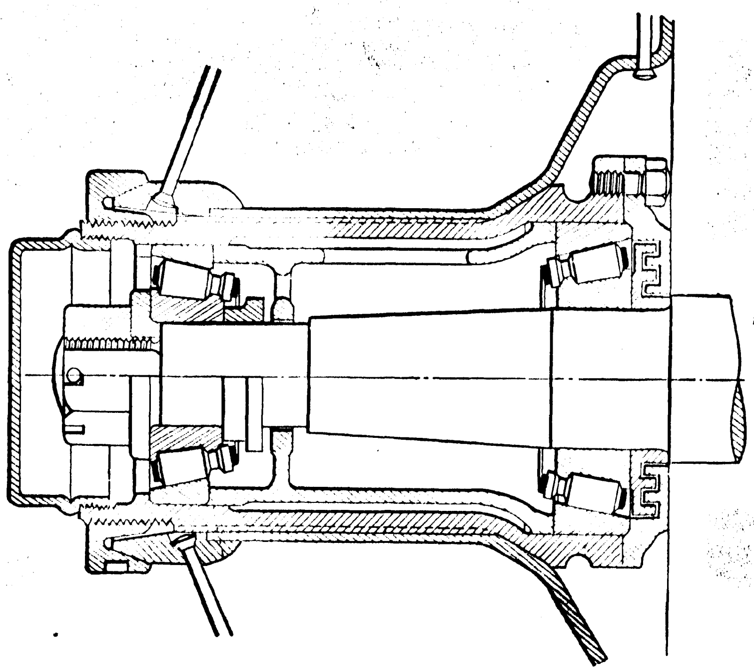


FIG. 50.—Timken roller bearing.

rubbing with their ends against the cage, so that these points require lubrication—more especially because the rollers often

create considerable end thrust. As such end thrust forces the cage against the inside of the bearing housing, lubrication is also required for these additional rubbing surfaces.

When the rollers are not absolutely parallel with the shaft, or if they are the least bit taper, or if the shaft or sleeve against which they revolve is taper, the rollers tend to roll in a helical path. They push themselves against one end of the casing until the pressure becomes sufficiently great; then they slip back suddenly and start rolling afresh in a helical path toward the same end of the casing as before. The amount of end thrust created is largely dependent upon the bearing load (it may be as high as 30 per cent of the load) and does not appear to vary with the amount that the rollers are out of truth.

The rollers have been known to wear right through their casing and nearly through the housing itself.

With change in direction of rotation the end thrust is always reversed. Speaking generally, the starting effort of roller bearings is only slightly greater than the running effort, but when there is considerable end thrust the starting effort may be even twice as great as the running effort.

The main evils of end thrust in roller bearings are:

1. It is largely the cause of the frictional resistance.
2. It causes excessive wear on rollers, cage, shaft, and casing.
3. It causes the bearing to run hot.
4. It sets up vibration and rumbling in the bearing and its housing.

The makers of the Hyatt roller bearings claim that one-half of the helical rollers will tend to run toward one end of the casing and the other half toward the other end and that end thrust is therefore eliminated.

Speaking generally, roller bearings—even the simplest types—develop less friction than plain bearings, provided, of course, that they are erected with a reasonable amount of care. Bearing housings should be self-aligning, so as not to set up undue stresses anywhere in the bearings.

To insure the best results, both ball and roller bearings must be very accurately fitted and, if worn, must be renewed and not allowed to run. If they are slightly out of line or slightly worn, great stresses are set up; the friction is high—may even be higher than with plain bearings—and the balls or rollers may break.

The coefficient of friction of roller bearings is always higher for small than for high loads and considerably increased when there is appreciable end thrust. It ranges from 0.002 to 0.007. The normal average values for the coefficient of friction may be taken as 0.003 to 0.004; but for bearings of the Hyatt type, the values are higher, ranging from 0.0045 to 0.007, the lower values corresponding to high loading.

Goodman summarizes the general results of his tests of roller bearings as follows:

1. The coefficient of friction of roller bearings is greater at low than at high loads, but it is much more nearly constant than it is in plain, lubricated bearings.
2. The coefficient of friction of roller bearings in which there is pure rolling is very nearly constant at all speeds; but when there is end thrust, the friction decreases as the speed increases.
3. The coefficient of friction is independent of the temperature of the bearings unless the end thrust is excessive.
4. The starting effort is very little greater than the running effort.
5. The friction in a well-designed bearing is not greatly affected by lubrication.
6. The wear of the rollers is often excessive if the whole of the rotating parts and the casing are not hardened and well finished, especially when the bearing shows end thrust.
7. The end thrust on the rollers varies almost directly as the load on the bearing and usually diminishes as the speed increases. The direction of the thrust is usually reversed when the direction of rotation is reversed.
8. Other things being equal, the frictional resistance of bearings fitted with large rollers is less than with small rollers.
9. The safe load for a given bearing diminishes as the speed of rotation of the rollers increases.

BALL BEARINGS

Ball bearings cannot create end thrust; herein lies one of their great advantages over roller bearings, particularly at high speeds. They are less inclined to heat than roller bearings, as the friction is lower. The starting effort is the same as the running effort, and, in consequence, ball bearings, notwithstanding that they have only point contact as compared with line contact in roller bearings, are able to sustain as heavy loads as roller bearings.

Ball bearings must not be adjustable; once the bearing is assembled, all running clearances must be correct, and neither the balls nor the races must wear.

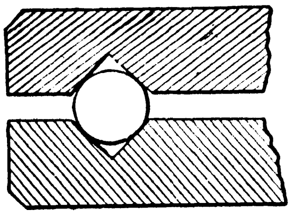


Fig. 51.—Four-point contact ball bearing.

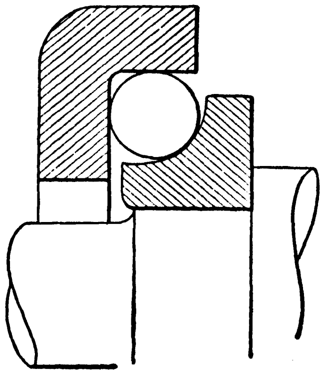


Fig. 52.—Three-point contact ball bearing.

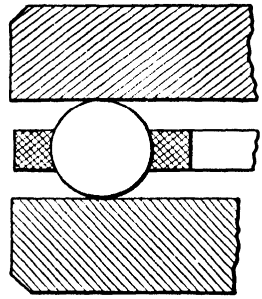


Fig. 53.—Two-point contact ball bearing.

Four-point and three-point contact bearings (Figs. 51 and 52) are not so satisfactory as two-point contact bearings (Fig. 53) for the reason that there is a grinding action between the balls and the races, and the balls get scratched. Two-point contact bearings may have flat races, as Fig. 53, and the results are very satisfactory; in fact, the coefficient of friction is lower than in other types of bearings, but the load-carrying capacity is 2 to 2½ times greater with grooved races, as in Fig. 54. With flat races the coefficient of friction decreases with increase in load, but with grooved races it may increase, possibly owing to the increased area of metallic contact between the balls and the races. For heavy loads the grooved races are to be preferred, given good alignment and workmanship; but if there is any doubt as to these points, flat (or cylindrical) races may prove better, as a slight lack of alignment will not affect the balls on a flat surface but may cause them to jamb and get cracked when running in grooved races.

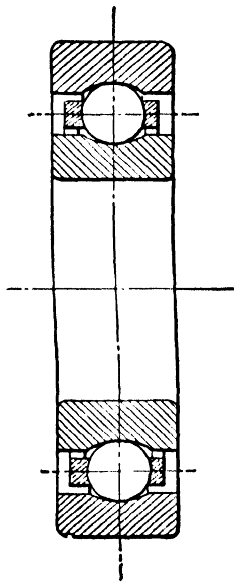


Fig. 54.—Ball bearing with grooved race.

Goodman has found that the friction in ball bearings is never reduced by lubrication but is sometimes greater than when the bearings run dry. Bearings with flat races have run dry for long

periods without any apparent ill effects; but bearings with grooved races soon begin to whistle and grind, probably because there is more actual rubbing between the balls and the grooves than with flat races. As, however, the absence of lubricant means that the surfaces in time will rust, which is fatal, lubrication is always provided.

It is important that the balls shall be all of the same size; if some of the balls are smaller than others, the big balls have to take more than their share of the load (being bigger, they get more squeezed than the little ones); the smaller balls take less than their share, therefore slip more, and it is this slipping that causes the balls to deterioate and get scratched.

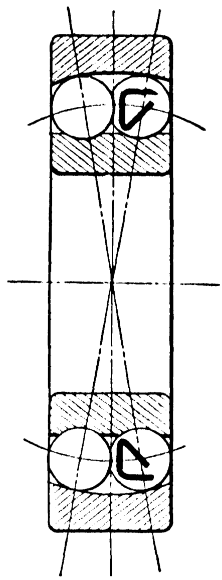


FIG. 55.—Skefko swivel bearing.

All the best makers will guarantee first-class balls to be accurate within 0.0001 in..; it does not matter much whether 1-in. balls are slightly more or less than 1 in. in diameter, but they must all be *exactly alike*, and with properly made bearings the wear will then be practically nil.

When balls are overloaded they become covered with tiny flakes of "snow," the flakes being tiny crystals which have broken away from the surface of the ball; these specks can be seen only under the microscope with 300 to 400 diameters magnification. When a ball finally breaks down it peals on one hemisphere and, curiously enough, usually only on the one hemisphere.

The question of alignment of ball bearings is as important as in the case of roller bearings, if not more so. The bearing housings are therefore usually made self-aligning, but in one type of bearing—the Skefko—the spherical outer ball race (Fig. 55) allows the inner race and balls to swivel out of their plane of rotation, so that they can adjust themselves to any lack of alignment of the shafting, whether due to bending or due to bad erection, and the adjustment will of course take place with much greater ease than in the case of a self-aligning bearing housing.

This bearing has other features. As there are two rows of balls, the load is distributed at any instant over three balls instead of

on one or two, as in an ordinary ball bearing; this feature increases the load-carrying capacity. The bearing is also capable of taking a certain amount of end thrust, as the balls touch the spherically shaped outer race at points where the pressure between them is at a slight angle with the vertical plane.

The inner race of a ball bearing must not be slack on the shaft; the shaft should preferably be ground to a light tapping fit for

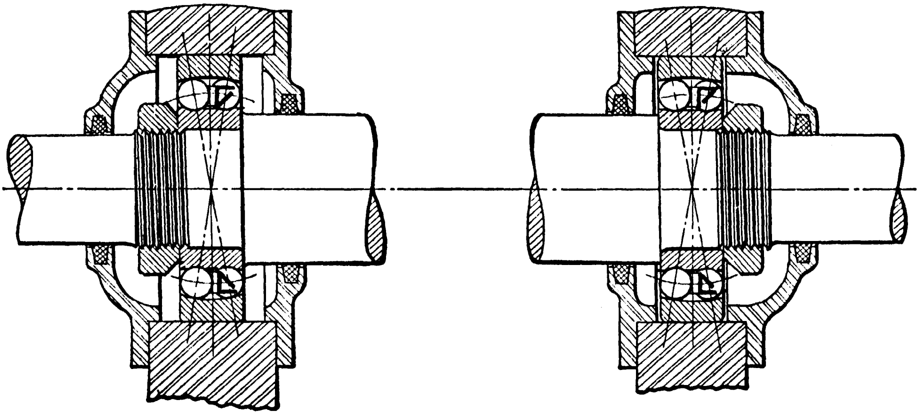


FIG. 56.—Ball bearings for electric motor.

the inner race, and the bearing secured against a shoulder by means of a nut (see Fig. 56). The outer race must not be a driving fit in the housing but should have an easy sliding fit, as otherwise the balls will be unevenly loaded.

Figure 56 shows the correct method of mounting ball bearings on an electric motor; the right-hand outer race is not allowed much movement between the housing covers, but the left-hand one has freedom to slide in its housing when the shaft expands or contracts.

The coefficient of friction of ball bearings is always greater with small than with high loads; it ranges from 0.001 to 0.003, the normal average value being 0.0015 to 0.002.

Goodman summarizes the results of his tests of ball bearings as follows, and his interesting remarks concerning a comparison between ball and roller bearings are also quoted:

LAWS OF BALL-BEARING FRICTION

1. The coefficient of friction of ball bearings with flat races decreases, and with grooved races sometimes increases, as the load is increased; but it is much more constant than that of plain, lubricated bearings.

2. The coefficient of friction of ball bearings is practically constant at all speeds but has a slight tendency to decrease as the speed is increased.

3. The coefficient of friction is independent of the temperature of the bearing.

4. The starting effort is practically the same as the running effort.

5. The friction in a well-designed bearing is very slightly higher when the bearing is lubricated than when it is dry, but in badly designed bearings the friction, when they are lubricated, is lower than when they run dry.

6. The wear on the balls when they are not overloaded is extremely small and is almost negligible.

7. There is no end thrust on ball bearings.

8. Other things being equal, the frictional resistance with large balls is less than with small balls.

9. The safe load for a given bearing diminishes as the speed of rotation of the balls is increased.

The foregoing statement by Professor Goodman that the wear on ball bearings, when not overloaded, is almost negligible must be qualified in the light of modern practice, as ball bearings today are sold to last a certain number of hours. The life is inversely proportional to the cube of the load; thus, if the load is halved, the life increases eightfold.

Common sense therefore dictates that a ball bearing be chosen that will last as long as the machine in which it is employed.

Comparison of Ball and Roller Bearings

Friction.—In general, the friction of ball bearings is considerably less than that of roller bearings, but both are very much better in this respect than plain bearings with ordinary lubrication.

The coefficient of friction of ball bearings is slightly less than that of plain bearings in a bath of oil.

End Thrust.—There is no end thrust on ball bearings, but in many roller bearings it is often quite serious in amount.

Space Occupied.—Most roller bearings are longer for a given load-carrying capacity than ordinary plain bearings. Ball bearings are, as a rule, much shorter and occupy much less space than even the best plain bearings.

Shafting Mounted on Ball Bearings.—For long lines of shafting, carrying pulleys and couplings, ball bearings are not so convenient as roller bearings. If a ball bearing on such a shaft fails, it is impossible to replace the ball races without taking down at least one length of the shafting, removing the couplings and pulleys, and fitting a new bearing. But with roller bearings, which are often used without a sleeve, there is no difficulty in replacing the whole bearing or any part of it without disturbing the shafting, because both

cage and bearing liner are nearly always made in halves, a practice quite out of the question with ball bearings, in which extreme accuracy is required.

With long lines of shafting, provision must be made for the expansion and contraction of the shaft. When plain, *i.e.*, not grooved, bearings are used there is no difficulty, but with grooved bearings the outer ring must be mounted in a housing in which it can slide. The efficiency of power transmission by shafting mounted on ball bearings is higher than can be obtained by any other known means.

Lubrication of Ball and Roller Bearings

On page 181 the various forms of friction that exist in a roller bearing are outlined, and it is obvious that in most roller bearings, owing to existing or possible end thrust, lubrication must be provided to reduce friction between the various rubbing surfaces.

In ball bearings there is less friction because of the absence of end thrust, but there is a certain amount of friction between the balls and the sides of the cage pockets in which they revolve. One form of friction that exists both in ball and in roller bearings has not yet been touched upon; it is due to the fact that balls, rollers, and races are somewhat elastic and that consequently instead of point and line contact we actually get metallic contact over a small circular and rectangular area for balls and rollers, respectively. The metal in front of and behind a roller, for example, is pushed up, as shown exaggerated in Fig. 57; the surface of the race is slightly stretched where it touches the roller; and when the metallic contact ceases, the surface contracts. At this point a certain small amount of rubbing therefore takes place between the roller and the race. It will be recognized that in front of the roller a similar small amount of rubbing takes place, as the surface of the race coming into contact with the roller becomes stretched. It will be seen that the stretching and the unstretching of the race in front of and behind the roller both tend to impede the progress of the roller and therefore create resistance.

When the surfaces of the balls or rollers and races are very hard and lack elasticity, this kind of friction is less than with more elastic surfaces but is always very small. Lubrication of these points is difficult, as the pressures must be very great; but even if lubrication of the rolling surfaces makes them more slippery, it must not be overlooked that compared with dry

surfaces we are adding a certain amount of fluid friction. It is a fact that the total amount of friction remains very much the same whether the surfaces are lubricated or not.

As has already been mentioned, lubrication of ball and roller bearings is imperative to prevent rusting and to maintain the balls, rollers, and races in a clean and highly polished condition. The entrance of moisture and dust must also be avoided, so that in humid or dirty surroundings the bearings must have efficient dust guards, or they must be completely filled with lubricating grease. In the latter case a fillet of grease will be formed at either end which seals the bearing against the entrance of dust and moisture.

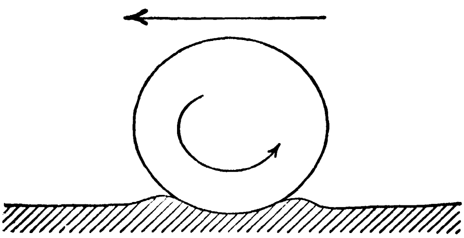


FIG. 57.—Rolling friction.

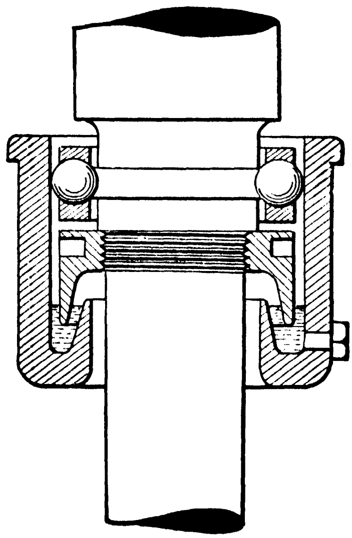


FIG. 58.—Vertical ball bearing, with oil-bath lubrication.

Figure 58 shows the application of a ball guide bearing to a vertical shaft; the housing is formed as an oil reservoir, and during operation centrifugal action forces the oil to rise and lubricate the balls.

Figure 59 shows a vertical ball thrust bearing fitted for grease lubrication; with slight alteration this bearing could also be designed with oil lubrication without danger of oil's overflowing down the shaft.

Figure 60 shows a ball thrust bearing which may be used horizontally or vertically and in which the shaft is allowed to swivel slightly on the surfaces indicated by the dotted circular line. These surfaces are ground and are submerged in oil. This arrangement will permit slight self-adjustment and make the running easier.

Figure 61 shows an axle box with a Skefko ball bearing as used on a Swedish railway (Karlsbad-Munkfors Railway). The axle

box is completely filled with grease, and it has not been found necessary to inspect and replenish with grease more than once or twice a year.

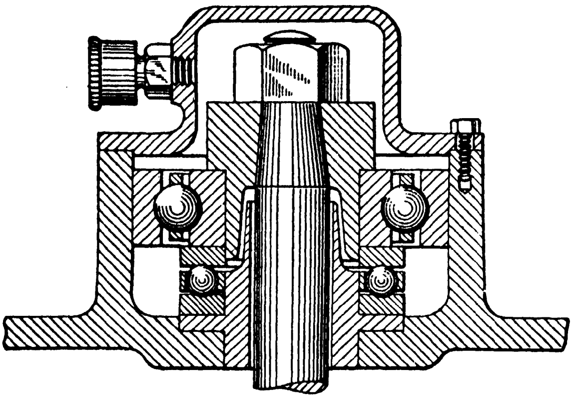


FIG. 59.—Vertical ball thrust bearing.

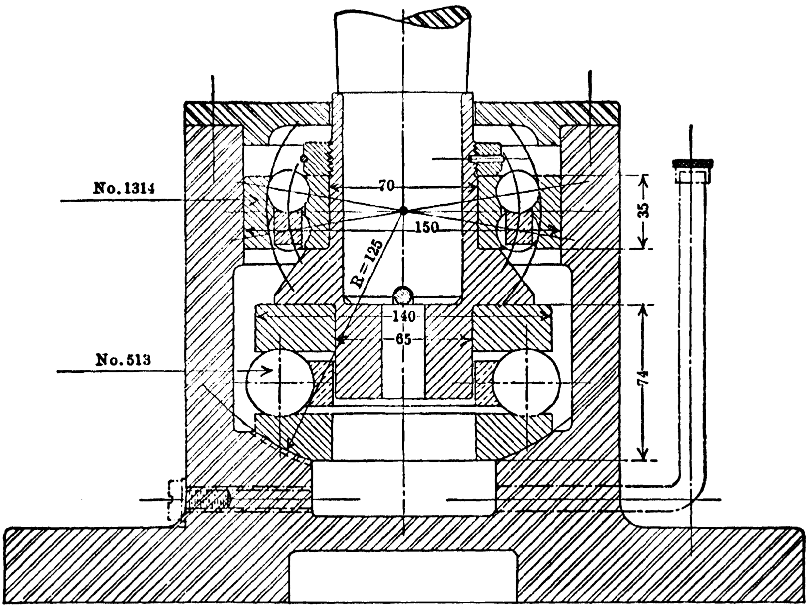


FIG. 60.—Self-adjusting ball thrust bearing.

Figure 62 shows a ball footstep bearing used for mortar mills in India, grinding refractory material. The dust is very hard and is kept out from the bearing by means of an oil seal, as shown, which can be removed for cleaning purposes. These bearings are reported to give complete satisfaction.

It is extremely important, when handling ball or roller bearings, to prevent dirt, filings, etc., from getting into them; many failures

of bearings have been caused by carelessness of this kind. When, for example, bearings are "cleaned" in the average motor-car repair shop, they are often dipped in dirty kerosene full of all sorts of sediment and impurities which get stirred up when the bearings are cleaned.

A good cleaning agent is made from soda and boiling water (1 lb. of soda to 25 lb. of water); the bearings may be dipped several times to remove all grease and dirt, then immersed in clean kerosene and given a swirling motion, when all surfaces should appear bright and clean.

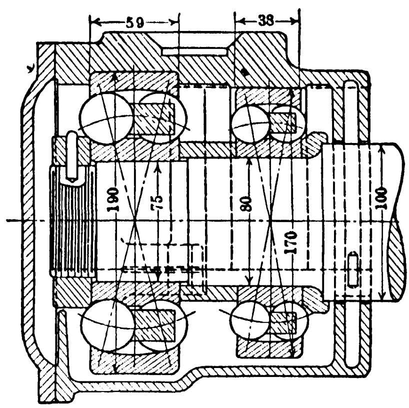


FIG. 61.—Skefko railway axle box.

Many automobile bearings have been ruined by wearings from the gears or impurities introduced when the gear case or rear-axle case has had its lid removed for inspection. Hence the design of oil filler as shown in Fig. 186 (page 511) is to be recommended, also from the point of view of the safety of the ball or roller bearings, now so frequently employed in gearbox or rear-axle constructions.

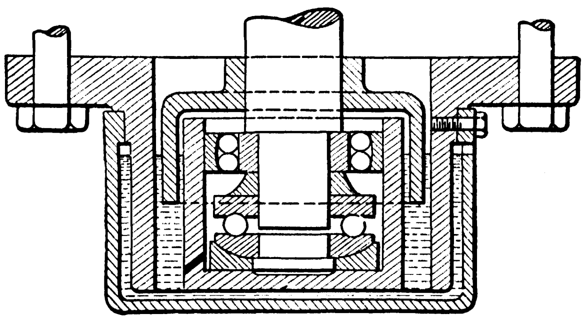


FIG. 62.—Oil-sealed ball footstep bearing.

When washing motor cars with water at great pressure, it is quite easy for the water to enter some of the bearings (which may not be completely filled and sealed with grease) and cause rusting, with the almost inevitable result that the bearings are destroyed.

As to whether oil or grease is to be employed, it appears to be preferable, wherever the surrounding air is reasonably clean and

not too humid, to use oil. The fitting of a dust guard in the form of a felt packing is always advisable; the oil keeps the balls clean and must be an acid-free, pure mineral oil so as not to gum or corrode the surfaces. It should be sufficiently viscous not to cause excessive oil spray, but oil spray may also be caused by overfilling the bearings. As the friction in ball bearings is not influenced by the viscosity of the oil, the selection of oil may be entirely governed by the other conditions mentioned; of course when the oil is carried to the surfaces by centrifugal action it must not be *too viscous*, and at low temperatures the oil must have a reasonably low setting point, so as not to congeal in the bearings.

In roller bearings, particularly those in which a certain amount of end thrust is created, mineral oils of heavy viscosity *must be used* for high temperatures, low speeds, or heavy loads, to minimize wear. Compounded oils would give better lubrication than mineral oils but must not be used, for the reasons mentioned above.

When bearings are exposed to high room temperatures, say much above 140°F., the oil will oxidize in time and may produce a carbonaceous deposit; for such conditions, the oil must be changed at sufficiently frequent intervals to prevent trouble, whereas ordinarily the oil need not be changed more often than every 3 to 6 months.

Grease is often used, and should be used, when bearings operate in a dusty or very humid atmosphere. The grease must fill the bearing cavity completely but must not be forced in so tightly as to impede the movements of the balls or rollers; high-speed bearings have been known to develop abnormal heat due to this cause. Replenishing with grease should preferably be done with small quantities at a time; if a big amount of grease is forced in by the grease gun or grease cup, trouble of the kind described is apt to occur.

When the grease chamber is filled for the first time, the grease may be melted by gentle heat (immersion in boiling water) and poured into the bearing; but when high-melting-point, fibrous greases are used, this practice is not to be recommended.

The grease must be as nearly neutral as possible, containing neither acid nor alkali, and it is essential that during manufacture it has been strained to remove all solid impurities.

The grease must not contain any filler, as chalk or gypsum, nor must it contain an excessive amount of water; in good-quality boiled greases the water content is less than 1 per cent and will not cause rusting, as in grease-filled bearings the air has no access to the surfaces.

Some greases are quite free from water, being simply petroleum jelly or mixtures of this material with mineral oil in various proportions. The melting points of such greases are very low; the melting points of boiled greases—cup greases and fibrous greases—are higher, particularly for the latter type which are therefore used under conditions of high room temperatures.

The grease should be of as soft a consistency as possible, say No. 1 or 2 at the running temperature, so as to penetrate and cover all parts inside the bearings. Many automobile bearings have been ruined because too viscous greases have been employed, which cannot possibly penetrate to the points required.

At one time many manufacturers of ball and roller bearings favored the use of mineral-jelly greases because of their freedom from moisture, but the general experience with these mixtures of mineral jelly and mineral oil has not been satisfactory on account of their deficient lubricating properties. For ball bearings with flat races which require hardly any lubrication, such greases have answered the purpose fairly well; but when some lubricating power is required, boiled lime greases, either cup or fibrous, are much to be preferred.

For heavy-duty roller bearings such greases should be made from a viscous mineral oil like bearing oil 5; whereas for light-duty roller bearings and for all ball bearings an oil like bearing oil 3 is to be recommended.

Solidified oils must never be used for ball or roller bearings, as they are not nearly so uniform as the boiled greases; they frequently contain a slight excess of alkali or acid in tiny pockets owing to the ingredients' not being so thoroughly mixed and combined as is the case in boiled greases.

Lubrication Chart

For Ball and Roller Bearings

Bearing Oil 2.*—For small and medium-size ball bearings and for small roller bearings with little or no end thrust.

* For bearing oils, see p. 135.

Bearing Oil 4.—For large ball bearings and for smaller ball bearings in which bearing oil 2 causes excessive oil spray or leakage.

For small or medium-size roller bearings with end thrust.

For large roller bearings with little or no end thrust.

Bearing Oil 6.—For roller bearings heavily loaded and with end thrust or exposed to high temperatures.

Cylinder Oil 2 *F.S.M.* (see table, page 408).—For roller bearings under extreme conditions of pressure or temperature.

Cup Grease 1 (made with light oil).—For small ball bearings.

Cup Grease 2 (made with light oil).—For medium- and large-size ball bearings and for small roller bearings with little or no end thrust.

Cup Grease 2 (made with viscous oil).—For all sizes of roller bearings.

Fiber Grease 2 (made with viscous oil).—For use in place of cup greases 1 and 2 when the bearings are exposed to high room temperatures.

CHAPTER XIII

MICHELL AND NOMY JOURNAL BEARINGS

The Michell principle described on page 174 has also been made use of for journal bearings, as shown in Fig. 63. The

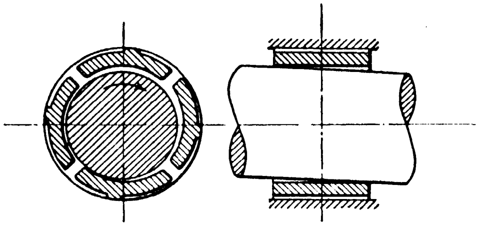


FIG. 63.

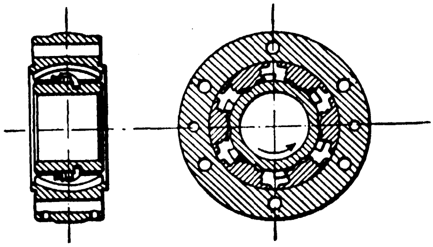


FIG. 64.

tilting pads ensure the same excellent formation of the oil film and low friction characteristic of Michell thrust bearings. The disadvantage is, however, that such a bearing allows the shaft to rotate in only *one* direction.

The construction of the Nomy bearing overcomes this difficulty (see Fig. 64). The name "Nomy" indicates that these bearings operate with very little friction—*i.e.*, no μ (my) = nomy.

The pads rotate with the inner ring, and every pad brings some oil with it from the oil reservoir in the base of the bearing housing (not shown). They have a spherical surface which ensures that they do not "edge" even if the shaft is bent or inaccurately mounted.

If the direction of rotation is reversed, projections on the inner ring will move the pads so that they tilt the opposite way and again are in the right position for drawing in oil and supporting the load in the same perfect manner.

Provisions are made for preventing the pads from moving sideways on the inner ring, and the special surface on the pads prevents them from dropping out sideways on the outer ring. As the inner ring and pads rotate and dip into the oil in the base of the bearing housing, the oil is violently thrown about and churned with the air inside the bearing.

This is bound to create oil foam and oil mist—the more so the greater the surface speed—it is therefore necessary to take special

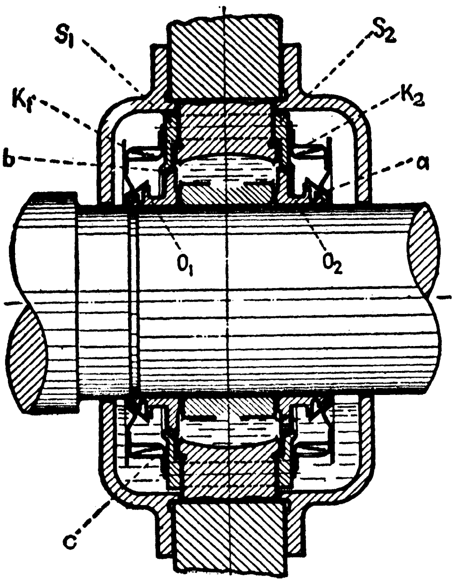


FIG. 65.—Nomy bearing. Baffle plate arrangement. The oil that leaves the bearing surfaces is retained inside the fixed baffle plates K_1S_1 and K_2S_2; the oil reaching the narrow spherical spaces *a-b* between the oil throwers O_1O_2 (which revolve with the shaft) and the baffle plates is constantly forced back and prevented from leaking out by the centrifugal force and the adhesion to the revolving oil throwers.

precautions against aerated oil's entering the bearing surfaces and against oil leakage out of the bearing.

Nomy bearings thus fulfill the following requirements which make them applicable for a very large range of service:

1. They sustain the load independent of its direction, so long as the load is directed approximately vertically against the shaft.
2. They operate satisfactorily notwithstanding the shaft's being bent or inaccurately mounted.
3. The axial length is so small that bending of the shaft inside the bearing does not affect the oil film.
4. They support the load independent of the direction of rotation of the shaft.
5. The coefficient of friction is exceedingly low, as the friction is entirely fluid.
6. The wear of the bearing surfaces is theoretically nil, and the life of the bearing unlimited.

CHAPTER XIV

STEAM TURBINES

HORIZONTAL STEAM TURBINES

Small turbines from 5 to 300 hp. operate at very high speed—from 3,000 to 30,000 r.p.m.—and are used for driving exhausters, exciter sets, small lighting plants, high-speed pumps, etc., both ashore and on board ships.

Large stationary turbines from 300 to 50,000 hp. operate at lower speeds—from 750 to 3,000 r.p.m.—and are principally used to drive electric generators in electric power stations, in collieries, steelworks, paper mills, textile mills, etc.

Marine steam turbines are used for the propulsion of nearly all warships, except submarines and some small naval craft. They are also used for the propulsion of steamers in mail and passenger service where high speed is essential. The use of a special type of marine steam turbine, *viz.*, the geared turbine, has come into great favor not only for warships but also for cargo boats.

Installations have been made of from 4,000 to 70,000 hp. in a single ship. Marine steam turbines are frequently constructed with high-pressure turbines, intermediate-pressure turbines, and low-pressure turbines, but sometimes there are only high-pressure and low-pressure turbines. It is usual to have two, three, or four propeller shafts, each shaft being driven by one or two turbines. On two of the shafts there are reduced-pressure astern turbines, which are used only for going astern. Generally, the low-pressure turbines are mounted on the same shafts as the astern turbines, close together with a common exhaust. Combinations may be made between reciprocating engines and marine steam turbines, the exhaust steam from the steam engines being used for operating the turbines.

The speed of marine turbines used in the merchant service varies between 160 and 300 r.p.m., whereas in naval practice the speed may be anything up to 600 r.p.m., and on certain turbines in the U. S. Navy the maximum running speed goes as high as 900 r.p.m.

Geared Turbines.—The geared type of steam turbine has been used in land installations but particularly for marine services. Installations have been made of from 4,000 to 30,000 hp. on a single shaft. The turbine operates at high speed similar to the ordinary land steam turbine and drives by means of gearing the propellor shaft at low speed. The result is that the steam is efficiently utilized in the steam turbine, and the propeller efficiency is also high, so that the combined efficiency is considerably greater than where steam turbines drive the propeller shafts direct.

The Ljungstrom turbine is a special type of geared turbine operating at very high speed, say from 4,000 to 7,000 r.p.m., driving through gearing two electric generators. When used in marine service the electric current produced drives high-speed electric motors, say, 900 r.p.m., coupled through gearing to the propeller shafts (operating at, say, 90 r.p.m.).

Types of Turbines

Parson's-type Turbines.—These turbines have a great number of revolving and stationary disks, the steam acting on the blades more by its pressure than by the speed at which it impinges on the blades. The speed rarely exceeds 3,000 r.p.m.

De Laval-type Turbines.—These turbines have only one revolving disk; the steam passes through several nozzles and impinges on the blades with very high velocity, the action being similar to that of a Pelton wheel. The De Laval turbines run at a speed of 10,000 to 30,000 r.p.m.

The Parsons and De Laval types of turbine represent fundamentally different principles of operation, and all other types of turbines are adaptations or combinations of these two principles. The difference in design, however, affects only the arrangement of the revolving and stationary disks, steam distribution to these disks, etc., and does not greatly influence the methods of lubrication.

Steam.—According to the steam used, turbines are classified as follows:

1. High-pressure steam turbines.
2. Exhaust steam turbines.
3. Mixed-pressure steam turbines.

1. *High-pressure steam turbines* take steam direct from the boilers. The steam after leaving the boilers is frequently superheated.

2. *Exhaust steam turbines* principally use the steam exhausted from reciprocating engines, *i.e.*, steam hammers, rolling-mill engines, or colliery winding engines. The pressure of this steam is only a few pounds per square inch. Before entering the turbine the steam passes an accumulator, which causes a steady flow of steam to the turbine. Exhaust steam is always very moist, carrying fine particles of water in suspension.

3. *Mixed-pressure Steam Turbines.*—Where there is not sufficient exhaust steam to operate a turbine regularly, or where the supply of exhaust steam varies considerably and at times becomes inadequate, the requisite quantities of high-pressure steam are automatically admitted to the turbine; hence the name "mixed-pressure steam turbines."

Where exhaust steam is taken from large steam engines, it is important that the steam be thoroughly freed from cylinder oil and impurities before entering the turbine, as otherwise the turbine blades will be coated with oily deposit. The turbine blades can be cleaned easily by injecting at regular intervals, by means of a hand-operated pump, from 1 pt. to 1 qt. of kerosene per week. When the steam is very dirty or greasy a maximum amount of 1 pt. per 12 hr. should suffice.

LUBRICATION

Owing to the high speed at which all turbines operate and to the fact that very little wear may cause disastrous results, the question of proper lubrication of the turbine bearings is of the greatest importance. If the oil supply fails, even for a very short period, or should the lubrication for other reasons become momentarily defective, the bearing in question will heat up quickly, and seizure will occur almost certainly before it is possible to stop the turbine. As a rule, turbine bearings either operate at a fairly normal temperature, or they are dangerously warm; for this reason every possible precaution should be taken to ensure a never failing supply of oil of the highest quality to each individual bearing, and the bearing should be carefully designed with a view to giving the oil every chance to distribute itself quickly over the entire bearing surfaces. Turbine oils must be specially manu-

factured to withstand the destructive action of water, impurities, and air during continuous service.

Lubricating Systems. *Drop-feed Oilers.*—In the early days of the turbine, the bearings were fitted with sight-feed drop oilers, which could be regulated to give a certain number of drops per minute, the feed being entirely by gravity. As, however, the feed varied with the height of oil in the oil container, the oilers needed constant attention in the way of adjusting the needle valves controlling the feed or filling up of the oil reservoirs. Apart from this, the "drop-feed method" soon showed its shortcomings when bearings were inclined to be troublesome, which was not infrequently the case, necessitating an increased oil feed and extra-close attention on the part of the attendant.

The real cause of the small margin of safety was that the friction was high owing to the high surface speed and, furthermore, that all the heat in the bearing had only one way of escape, *viz.*, through radiation to the engine room from the outside of the bearing housings and pedestals. The bearings were always operating at a temperature much above that of the engine room, partly due to the frictional heat developed in the bearings, and partly due to the heat conducted through the turbine shaft.

Ring Oiling.—In modern turbine practice the drop-feed method has been almost entirely superseded by continuous force-feed oiling systems, and in the case of some few makes of small turbines ring-oiling bearings have been adopted for turbines below 200 h.p.

A more positive system than the ordinary ring-oiling arrangement is illustrated in Fig. 66, the oil ring (1) having a "U" section, and the oil being continuously diverted into the bearing by the stationary oil scoop (2). If the oil well contains a fair quantity of oil, the heat can be readily conducted to the bearing pedestal and radiate into the engine room without the bearings' getting uncomfortably warm. Water cooling of the oil has been resorted to in some cases with very good results: (*a*) in the shape of a cooling coil in each bearing pedestal; (*b*) by casting the two bearing halves with cavities for water circulation; or (*c*) by having a central oil cooler and an oil pump forcing the oil through the cooler and thence into the various bearing oil wells. The oil overflows from each bearing back into the tank from which the oil pump draws its supply and circulates the oil afresh. Using

ordinary ring-oiling bearings without water cooling is, of course, cheaper than a forced-feed circulation system but does not give the same margin of safety. Care should be taken that the oil is changed at intervals of, say, 3 months. If the oil is of good quality, it can be used over again after proper separation from water, dirt, and other impurities in a steam-heated settling tank, followed by filtration through an efficient steam-heated filter.

Force-feed Circulation.—This system is in general use for practically all turbines above 200 hp. Only in very rare cases

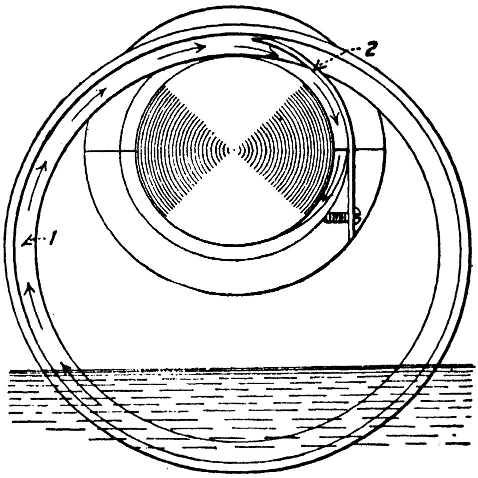


FIG. 66.

has the oil been forced into the bearings at the points of greatest pressure, lifting the shaft of the rotor and thereby keeping it "floating." In order to accomplish that, an oil pressure somewhat higher than the maximum bearing pressure per square inch is required. If several bearings are fed from the same oil-distributing pipe, they must all have approximately the same load per square inch, as otherwise the bearing with lower bearing pressure would rob the other bearings of a portion of their share of the oil supply, the oil naturally taking the way of least resistance.

The term "force feed" therefore generally means that the oil is kept in circulation by means of a pump at a pressure usually much below the bearing pressures. The oil is introduced at the top, or "on," side of the bearings and wedging itself in between the revolving shaft and the bearing surfaces produces a complete oil film on which the whole weight of the revolving part "floats."

If a continuous flow of oil through the bearings is provided, the oil carries away not only the greater portion of the frictional heat but also the heat conducted through the shaft from the highly heated parts of the turbine. The combined loss from friction and heat transmission into the bearings is estimated at about $\frac{1}{3}$ per cent of the rated horsepower of the turbine.

The Oil Cooler.—It therefore becomes necessary to cool the return oil from the bearings, and it cannot be too much emphasized that an efficient, well-designed oil cooler of ample capacity is one of the best investments that can be made in a turbine plant and is an excellent insurance against lubrication troubles. There is a variety of designs of oil coolers. In the early days they were often "built in" in the bedplate. This practice seems now to be practically abandoned; because of the proximity of cold water and hot oil, extra stresses are set up in the turbine bedplate, owing to the unequal expansion of the various parts, and a cracked bedplate has occasionally been the result.

Another reason for building the oil cooler separate from the turbine is the vibration which tends to disturb joints, etc. One curious result of heavy vibration was the wearing through of a cooling coil rubbing against the bottom of the oil cooler; it was finally perforated, and the water leaking into the oil caused considerable trouble. When a new coil was fitted it was raised above the bottom and had small "feet" clamped on to it at intervals. This successfully overcame the trouble.

Oil coolers should be designed with a view to facilitating inspection and cleaning of the tubes, internally as well as externally, and the water spaces. The oil cooler should always have doors for inspection, large enough so that the tubes can be cleaned on the outside. The tubes should be solid drawn, seamless, with no unnecessary connections, which might cause leakage; frequently they are so arranged that they can be withdrawn as a whole for inspection and cleaning.

In the earlier type of coolers the tubes were usually of the U type, but most modern coolers have straight tubes, which are easier to clean. The flow of oil and water through the cooler should always be in opposite directions, so that the oil in passing through meets colder and colder water; in this way the best cooling effect is obtained. In most coolers the oil is inside the tubes.

It is highly desirable that the pressure of the oil in passing through the cooler should at all points be higher than the water pressure, so that should any leakage occur it will be of oil into water; otherwise, it will mean water leaking into the oil, which must be avoided for reasons given later on.

The capacity that hot oil, in particular, possesses of percolating through the most minute pores or leaks is remarkable, and leakage may occur under running conditions, even if the cooler has been tested cold and found perfectly tight under great pressure. When testing an oil cooler for leakage it should, therefore, always be tested "hot."

The cooling coils sometimes get badly corroded when acid water is used, and corrosion nearly always attacks certain spots in the tubes, particularly if the latter are made of brass. It looks as if local galvanic currents may often have something to do with heavy corrosion, caused by inequalities in the composition of the tube metal and due to the presence of small grains of different metals close together—copper, zinc, etc. To prevent corrosion in oil coolers employing sea water, an iron rod fixed from end to end of the cooler has proved effective; the rod is often eaten away by galvanic action in a single voyage.

The cooling water should preferably be circulated through the cooler by means of a circulating pump and at a low pressure, which falls to nil when the turbine stops running. The efficiency of the oil cooler is greatly affected by dirty cooling water; cases have been known where greasy, muddy river water—caused by dirty discharges from works higher up the river or due to heavy rainfall—used as cooling water has deposited sufficient slime and dirt to increase the turbine oil temperature at the rate of 1°F. per day.

The oil cooler has its best place in the circulation system after the oil pump, not before,[1] as in the latter case the oil is sucked through the cooler, and any leakage would be of water into oil.

Thermometer pockets should be fitted in the inlet and outlet oil pipes, also in the water inlet and outlet to the oil cooler, as by temperature records taken, say, every hour it will at once be discovered if there is anything wrong with the cooler or with the oil in circulation. The water, if not clean, may have thrown down muddy deposits on the tubes, or the tubes may have been coated

on the "oil" side with deposits from the oil system. In any case, the temperature records will at once indicate whether trouble is approaching, and a close investigation in good time will locate the cause and point out the remedy.

Shutting off the cooling-water supply is the last operation when stopping a turbine, but the oiling should be continued until the turbine has come to a standstill.

If an oil cooler is found to be too small in capacity, it is not of much use to increase the flow of cooling water through the cooler; it will, of course, make some difference, but if the cooling water is taken from the coldest available supply, and if the oil does not get cooled sufficiently, the only remedy is to increase the capacity of the cooler by adding more "surface."

In some installations where the oil is inside the tubes an improvement has been made by fitting twisted strips—of the same material as the tubes—inside the tubes in order to disturb the oil as much as possible; it is obvious that as long as the flow of oil is only 1.0 to 2.0 ft. per second, which represents normal practice, the oil ordinarily shoots through the tubes without being "broken up," and a layer of cold oil on the inside of the tubes makes the cooling of the oil in the center rather inefficient. The value of inserting the twisted strips—retarders—will be easily understood.

The Oil Pump.—The development has been in the direction of rotary, toothed-wheel pumps driven by worm or skew gearing off the main turbine shafts. The toothed-wheel pump is more positive in action than the valveless "sliding-vane" type of pump; also, there is less chance of the toothed-wheel pump's being accidentally choked with rusty scale, dirt, etc., as the oil has a more effective washing action in passing through the pump. On the other hand, the toothed-wheel pump has the disadvantage that the oil is "churned" more vigorously and may consequently suffer more when water happens to be present.

The oil strainer consists of copper or brass gauze, supported by a perforated cylinder, which it covers. This cylinder should be of the same metal as the gauze, as otherwise galvanic action comes into force and destroys the strainer by pitting and corrosion. The oil strainer should be situated in a position well clear of the bottom of the oil tank, say 4 to 6 in., to allow the water which almost invariably leaks into the oil to separate out, so that it can

be drained away through a drain or sludge cock of ample dimensions—not less than 1½-in. bore. The need for such a big bore is on account of the sludge, which may be formed in the oil, and which will not drain out through a small opening. If the strainer is placed close to the bottom of the tank, water is sucked into the pump first of all and is not given a chance to separate out from the oil. Care should be taken to have sufficient oil above the top of the strainer so that no air can be drawn in with the oil, as aeration of the hot oil has an oxidizing effect and may cause decomposition of the oil, if the temperature is high.

In large installations the oil pumps are nearly always operated separately from the turbine, either electrically or by steam; the pumps are started up before the turbine and kept in operation until the turbine has come to a standstill. In smaller installations, where the oil pump is an integral part of the turbine, the pump will not supply a sufficient quantity of oil until a certain speed has been reached; it therefore becomes necessary to have an auxiliary oil supply which works independently of the turbine-driven oil pump. This auxiliary supply is usually a hand pump, with which the bearings can be flushed before and during the starting up of the turbine; in larger installations a hand-operated pump becomes inadequate, and the auxiliary oil pump is driven by an electric motor or by steam. It cannot be too strongly emphasized that the bearings should be continuously flushed until the speed of the turbine is about 20 to 25 per cent of the normal; this should also be done when in stopping the turbine the speed has fallen to the speed just mentioned. By watching the pressure gauge attached to the main circulating system, the attendant can always be guided as to the time when it will be safe to discontinue the auxiliary oil supply.

The oil pump should be designed to give a supply of oil at the pressure required, equalling 0.05 to 0.15 gal. per min. per square inch of total projected bearing surface.

The strainer on the suction side of the oil pump should have an area in square inches equalling from four to six times the number of gallons of oil circulated per minute.

The quantity of oil present in the circulation system should be from 0.15 gal. per kilowatt for smaller turbines to 0.10 gal. per kilowatt for the largest units, but the minimum amount of oil in any turbine should preferably be 120 gal.

Oil Pressure and Circulation Systems.—On leaving the oil cooler, the oil generally goes to the main oil-distributing pipe, which runs along the turbine bed and from which branch pipes lead it into the various bearings. It is forced into the main oil pipe under a certain pressure which is regulated by means of a spring-loaded relief valve; this valve can be regulated to give any desired pressure within certain limits, and the surplus oil is allowed to discharge back into the suction oil tank.

Another way of maintaining a certain oil pressure is to force the oil up into an elevated tank, from which it is led through a main pipe down to the turbine and then distributed in the ordinary way. This system has the advantage that, should the oil pump fail for some reason or other, the top tank will continue the supply for a sufficient length of time to allow the turbine to be shut down before any damage is done. The top tank should be fitted with an overflow pipe to carry surplus oil down into the return oil tank. It should also have a drain or sludge cock of at least 1½-in. bore and a drain pipe.

The return-oil tank must be of sufficient capacity to take the whole of the oil in the system, in case during a standstill the whole of the oil in the top tank should be allowed to run down into the bottom tank.

Sight feeds are sometimes fitted in the inlet branch pipes to the bearings, their position being between the bearings and regulating cocks fitted in the inlet pipes. It is, however, difficult to keep them clean. If the oil drops through the sight feeds, it has a tendency to take the air away, and the sight feeds fill up with oil. The same unsatisfactory results are generally experienced where the sight feeds are filled with water and the stream of oil is made to rise through the water; the oil carries the water away, and the glasses fill up with oil.

It is, of course, very desirable to have efficient sight feeds, but it is preferable to fit them in the return-oil pipes from each bearing. Care should be taken that the outlets have ample openings to allow of the oil's running through freely; otherwise it cannot escape from the bearings quickly enough and overflows through the bearing ends. Some makers just fit onto each bearing a small test cock which if opened shows whether the inlet pipe is supplied with pressure oil or otherwise, but, of course, this does not give any idea as to how much oil goes through each bearing.

In plants with a top oil tank, distributing the oil by gravity, the oil pressure is a fixed figure; but where the oil is distributed direct from the oil pump, the maximum oil pressure that can be obtained depends upon the capacity of the pump and the resistance offered to the oil in its passage through the oil pipes and the bearings. The warmer the oil—or the thinner the oil in use—the lower will be the maximum oil pressure obtainable, as the thinner oil passes more easily through the bearings and leaks more freely in the case of a rotary oil pump; *i.e.*, the pump discharges less oil per revolution.

A lowering of the oil pressure of a dangerous nature may take place when unsuitable oil gets very thick and sludgy, owing to emulsification with water, particularly if the pump strainers are covered with sludge. Under these conditions a vacuum is formed in the pump; it "slips" and does not operate with its full capacity; hence the oil pressure falls, sometimes with only short warning, and may cause disastrous results. When a turbine starts up cold, the oil pressure is usually high, even if the relief valve is fully open; as the oil warms up, the pressure falls but should not fall more than can be met by partly closing the relief valve when the running temperature has been reached, thus leaving a margin over and above the minimum pressure required to operate the governor gear.

The cooling-water service should not be put on until the oil in circulation has warmed up to within 20°F. of its normal temperature.

As regards the oil pressure required for distributing the oil with certainty to the bearings, a few pounds per square inch will be found adequate to give a satisfactory supply, say from 5 to 15 lb. per square inch.

In many modern designs of turbines the oil is made use of in several other ways, the principal one being in connection with the operation of the governor gear. It is beyond the scope of this book to go into the various designs of oil-worked governor gears, but the author would like to emphasize the necessity of using good-quality oil and keeping it in first-class condition; otherwise, the result may easily be sluggish and unsatisfactory governing, as some of the clearances are exceedingly fine. One point worth mentioning is that, where a vertical spindle operates the steam-throttle valve below, the oil-worked piston being above

(see Fig. 67), the stuffing box of the oil cylinder invariably leaks slightly. If this oil is allowed to trickle down on top of the throttle-valve cover, it will smoke and "bake on" in the form of a carbon deposit, particularly when superheated steam is used; this is rather objectionable and may easily be prevented by fixing a cup on the spindle and a drain to carry oil away outside the throttle valve, as shown.

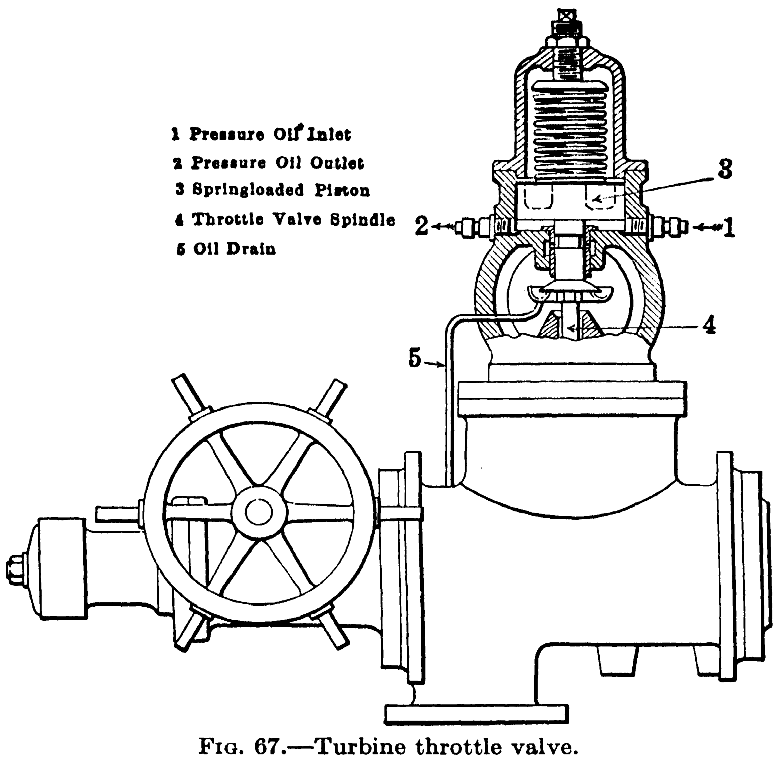


FIG. 67.—Turbine throttle valve.

The principle of operation of oil-worked governors embodies a pilot valve, which is moved by the governor, and which when moved allows pressure oil to flow into an oil-relay cylinder, thereby causing a spring-loaded piston to rise or fall in this cylinder, according to whether the oil is introduced above or below the piston or, if acting only on the underside, according to whether the oil is admitted or not. The piston, moving with great force, acts directly on the main steam valve. When the oil supply to the governor is taken from the main oil-circulation system, a failure of this oil supply will cause the relay piston to descend and shut off the steam supply operating the turbine.

The turbine cannot start until a sufficient oil pressure has been obtained in the oil-supply system, and consequently any damage to the bearings due to insufficient pump pressure is thus obviated.

The oil pressure required by the governor gear is high—from 25 to 60 lb. per square inch—in accordance with the requirements of the various designs.

Several makers fit two oil pumps—one delivering small quantities of oil under great pressure for the governor gear, the other delivering large quantities at low pressure for lubricating the bearings.

Oil Pipes.—The distributing-oil pipes should be of ample proportions, with as few bends as possible. The branch pipes leading to the bearings should not join the main oil pipe at right angles but preferably at an angle not more than 30 deg., with a view to decreasing the loss in oil pressure due to fluid friction and resistance.

As regards the return-oil pipes from the different bearings, they should be of ample proportions, so that the maximum quantity of oil from each bearing may return comfortably; otherwise, the oil may overflow through the bearing ends and cause unsightly waste of oil, with a possibility, in the case of turbogenerators, of the oil's being drawn over into the generator and spoiling the insulation. The branch pipes should meet the main return pipe at an angle of not more than 30 deg.; and in case of sight feeds in the branch pipes, these should be designed so that air does not get churned with the oil, causing aeration. At no place must the flow of oil be broken up or violently disturbed.

During late years most turbine makers have made the oil pipes of steel or wrought iron instead of copper, which originally was used exclusively. This has been done largely in view of lower first costs, but it is very questionable whether this step is an altogether wise one. The oil is nearly always charged with finely divided globules of air and water, and through the continued use it always becomes slightly acid. These features combined cause corrosion of the iron or steel pipes in a much higher degree than when the pipes are made of copper—in fact, copper is hardly affected (see page 226 and Example 6, page 232).

Bearings.—The load on the main bearings of a turbine is due mainly to the weights of the rotor, shaft, and generator, if any. The pressure is therefore the same, whether the turbine is

under load or otherwise, and is never relieved, as is the case with the principal bearings of reciprocating engines. It is consequently of the very greatest importance to design the bearings with a view to quick distribution of the oil, particularly in the case of marine turbines, where greater pressures per square inch are carried in connection with lower surface speed. A high surface speed draws the oil in between shaft and bearing and makes it possible, and desirable, to use free-flowing oils. On the other hand, the lower surface speed and higher bearing pressures met with in marine practice necessitate the use of heavier bodied oils and may even make careful oil grooving desirable.

With high surface speed, oil grooves should be dispensed with altogether, being distinctly detrimental, as they reduce the area of the bearing surface.

In some cases turbine bearings have been designed as oil-cooled bearings, the oil before entering the frictional surfaces first passing round the outer surfaces of the bearing shells. The result is that the bearings are kept at a uniform temperature throughout and that the oil removes a little more heat than it would have done had it been passed direct into the frictional surfaces.

Should a bearing give trouble, it generally gives no warning; the oil evaporates, and white fumes ooze out from one or both ends. The turbine should be stopped at once, as the white metal with all certainty has started to run and will want renewing before the turbine can be put under load again. Grit or dirt may have been the cause. Failure of the oil supply, if due to the oil pump's pumping an insufficient amount of oil, will show up in decreased oil pressure and should be noticed by the attendant. Choking up of one of the oil-distributing pipes to a particular bearing might be noticed in time, if the bearings are fitted with sight-feed attachments.

Whenever a bearing cap has been adjusted, the turbine should not be put on full speed until one is fully assured that the bearing does not pinch the shaft.

The amount of oil circulated per minute varies according to the oil pressure required and to the size of the bearings. Current practice is to circulate the oil at the rate of 0.05 to 0.15 gal. per min. per square inch of total bearing surface, as mentioned under the heading "Oil Pump." In the case of slow-speed marine tur-

bines, a supply of 0.02 gal. per min. per square inch will be found adequate. This lower rate of feed emphasizes, however, the desirability in the case of marine turbines of having oil sight feeds in the return pipes from each individual bearing to make sure that each bearing gets its proper share.

Turbine Thrust Bearings.—Where greater or smaller end pressure has to be taken up, owing either to the design of the turbine itself or to propeller thrust, the thrust bearing becomes an important feature of the turbine.

Thrust blocks for marine turbines are usually of cast iron, with a steel bush for holding the thrust rings. The top portion of the thrust block generally takes the steam thrust, and the lower portion the propeller thrust. The block is fitted on a sole plate of its own and can be moved in a fore-and-aft direction; also, the upper portion can be moved relatively to the lower portion in order to adjust the clearances of fore-and-aft play, which may be made about 0.01 in. The thrust rings may be made of gun metal with white-metal facings on the rubbing surface.

It is evident that when the thrust block is supplied with oil under pressure from the outer edges of the thrust rings, the oil has to go against the action of the centrifugal force, and when it is between the rubbing surfaces the tendency is to squeeze it out all the time; whereas in the main bearings of the turbine the revolving shaft draws the oil in between the rubbing surfaces, feeding it toward the place where it is needed. An increased oil pressure does not help the oil in the case of a thrust block; the oil has only its natural clinging property—oiliness—to depend upon for getting to the place where it is required.

Thrust blocks in steam-engine-propelled ships are lubricated by means of oils heavily compounded with vegetable oils. The reason is that such oils, properly manufactured, have very great clinging properties, so that they are able to get in between the rubbing surfaces better and more easily than pure mineral oils.

In forced-lubricated thrust blocks in connection with marine turbines the oil is taken from the main circulation system, as it would be cumbersome to make a separate oiling system for the thrust blocks. But oils used for forced lubrication must be pure mineral in character, and, in view of what is said above, it is obvious that a heavy-bodied oil will be needed for the thrust

blocks, as light-bodied pure mineral oils would cause the thrust bearings to run hot.

Another condition in connection with marine turbines that calls for more viscous oil than similar-size land turbines is the vibration, which is set up partly by the turbines themselves and partly by the reaction of the water on the propellers. Heavier vibration calls for better cushioning in the bearings, and this can be given only by employing a more viscous oil.

Thrust bearings of the ordinary type carry a maximum bearing pressure of 15 to 20 lb. per square inch in the case of land turbines and 30 to 50 lb. in the case of marine turbines.

Attempts have been made to introduce actual forced lubrication conditions in the thrust bearings, by making the oil pass through the hollow shaft and thence forcing it out between the revolving thrust rings and the stationary thrust block. Such a system has been designed by Ferranti and is said to have given excellent results, making it possible to carry great pressures without any fear of the bearing's seizing.

An ingenious method of getting over the difficulty with the thrust bearing has been designed by Franco Tosi. He balances the difference between the propeller thrust and the steam thrust by means of oil pressure exerted on the two sides of a piston which revolves with the shaft and is fitted with a labyrinth packing. Oil under pressure is constantly being forced into the chambers on both sides of the piston and can escape only between the collars of the thrust blocks at either side. If the thrust is from right to left, the clearances on the left-hand side are diminished, so that it is easier for the oil to escape between the right-hand thrust collars; consequently, the oil pressure becomes lower in the right-hand chamber, and the difference in oil pressure forces the piston to the right, or vice versa, thus automatically balancing the axial thrust and preventing metallic contact between the rings and the blocks. At high speed, fluid friction developed between the piston and its casing, etc., would be very considerable; but as marine turbines are slow speed, this loss is only small.

With Parsons steam turbines the axial thrust on the rotor is more or less balanced by the propeller thrust, and the thrust bearing embodied in the turbine itself gives no great difficulty; but with geared turbines, with the reintroduction of a main thrust block on the propeller shaft, the multicollar marine type of thrust bearing has failed to give satisfaction.

The even turning moment of the turbine transmitted through the gearing never pulsates or fluctuates, thus not giving the thrust collars that relief which in the case of a steam engine in some measure helps the oil to creep in between the rubbing surfaces.

For geared turbines, the thrust problem has been solved by the Michell single-collar thrust bearing, described on page 175, which will carry a bearing pressure of 400 to 500 lb. per square inch with the greatest ease and with a surface speed ranging from 60 to 100 ft. per second.

The Hon. Sir C. A. Parsons has designed a similar type of bearing, but with centrally pivoted segmental blocks, allowing the turbine shaft to revolve in either direction. The frictional losses in these types of bearings are considerably less than in the ordinary plain type of thrust bearing; the coefficient of friction may be taken as 0.002 as against 0.03 to 0.04 for ordinary thrust bearings.

Wear.—As turbine bearings are virtually flooded with oil, it is probable that the shaft never comes into actual rubbing contact with the bearings except at the moment of starting. When the turbine is standing, the oil film is pressed out, and actual contact between journal and bearing probably takes place; but as soon as the turbine starts running, the first few revolutions will build up the oil film, which, if the oil is satisfactory, will support the shaft; *i.e.*, it "floats" on the oil film.

Turbine bearings, *i.e.*, the vast majority, practically never wear. It sometimes happens that what may appear to be wear takes place for a certain length of time, after which it ceases; this is, in reality, due to compression of the white metal, which has been rather soft.

After many years' working, the toolmarks should still be visible if the turbine has had proper care and attention.

Temperature Records.—When a turbine starts from cold, the oil will gradually rise in temperature, rapidly at first, slowly later on; and if the conditions remain fairly uniform—uniform load, uniform temperature of cooling water and engine room—the maximum temperature will be reached after a certain number of hours, varying from 4 in the case of small turbines to 8 hr. or even longer in the case of large units. This final temperature is not much affected by changes in the engine-room temperature or

The temperature of the cooling water, however, and the state of cleanness of the oil cooler have a marked influence on the oil temperature, and naturally so, because it is in the oil cooler that the bulk of the heat is removed from the oil, a minor portion only being radiated into the engine room from the bearings, pedestals, oil pipes, oil tanks, etc.

The temperature of the oil in the main return pipe ranges from 100 to 140°F.—seldom below 100 and not often above 140°F. But bearings have run without trouble for long periods at temperatures as high as 160°F. However, it is desirable that the oil temperature should be about 120 to 130°F.

In the case of marine turbines, the oil temperature rises in the tropics as compared with conditions in temperate climates, owing to the higher temperature of the cooling water, being 70 to 85°F. as compared with 50 to 70°F. for temperate climates. The oil must, of necessity, rise in temperature in order that the difference in temperature between itself and the cooling water may enable the water to take away the heat from the oil.

It would be useless to quote actual temperature records from turbines in operation, as they vary exceedingly; *e.g.*, in some turbines the fall in temperature between the return oil and the oil leaving the cooler is as low as 4°F., owing to the fact that the amount of oil delivered by the oil pump to the bearings is high per square inch of bearing surface and to the fact that the bearing is water cooled.

In a good many turbines the difference in temperature between the outgoing and returning oil is from 15 to 20°F., and in some extreme cases, where the bearings have not been water cooled and the oil delivery per square inch of bearing surface has been low, this difference has been as high as 50°F. The temperature rise of the oil going through the worm-wheel casing (the worm-wheel shaft operating the oil pump, governor, and sometimes the circulating pump for the condensing plant) or the thrust bearing is usually considerably higher than the temperature rise of the oil going through the other bearings.

For each particular turbine the temperatures of the oil and water inlet and outlet to the cooler and of the oil inlet and outlet to the various bearings—or, as an alternative, the bearing temperatures at both ends of each bearing—indicate whether normal conditions of lubrication and cooling prevail.

Thermometer pockets filled with oil should be fitted in the positions mentioned above. In case of the return-oil temperatures taken in the bearing outlets, care should be observed that the flow of oil shall wash over the thermometer bulb or the pocket. Occasionally, the thermometers should be compared with a standard thermometer, say once a year. A temperature log should be kept in the engine room, taking the temperatures every hour.

The turbine attendants will very soon get to know by heart the normal running temperatures at the various points, and they will learn to interpret the correct causes of any deviations from the normal temperatures or, at any rate, to look in the right direction for the cause of irregularities, indicated by abnormal temperatures.

The Turbine Glands.—The most frequent cause of water's getting mixed with the oil in circulation is leakage of steam past the glands, the steam condensing on the shaft and bearings, gradually working its way into the main bearings and mixing with the oil. It will, therefore, be useful to look for a moment on the various designs of glands.

There are three types:

1. The labyrinth packing gland.
2. The carbon packing gland.
3. The water-sealed gland.

The function of the gland is either to keep high-pressure steam from leaking outward or, in the case of the "vacuum end" of the turbine, to prevent air from being drawn in, which would adversely affect the vacuum produced by the condensing plant.

1. The *labyrinth packing* (Fig. 68) consists of a series of rings on the shaft which alternate with stationary rings in the surrounding casing; there is only a very slight clearance between the shaft and the stationary rings.

The steam—in the case of a high-pressure gland—must pass the rings in a zigzag way, so that only a slight amount of steam escapes at the vent (1), which may be connected with an intermediary stage of the turbine or simply allows the steam to escape into the open. Any steam or water leaking outside the gland is deflected by suitable throwers fixed on the shaft in order to prevent the water as much as possible from getting into the adjacent bearing.

In the case of a low-pressure gland, steam at a reduced pressure—either from an intermediary stage or high-pressure steam throttled down to the required pressure—is introduced at (1) and leaks inward into the low-pressure turbine casing.

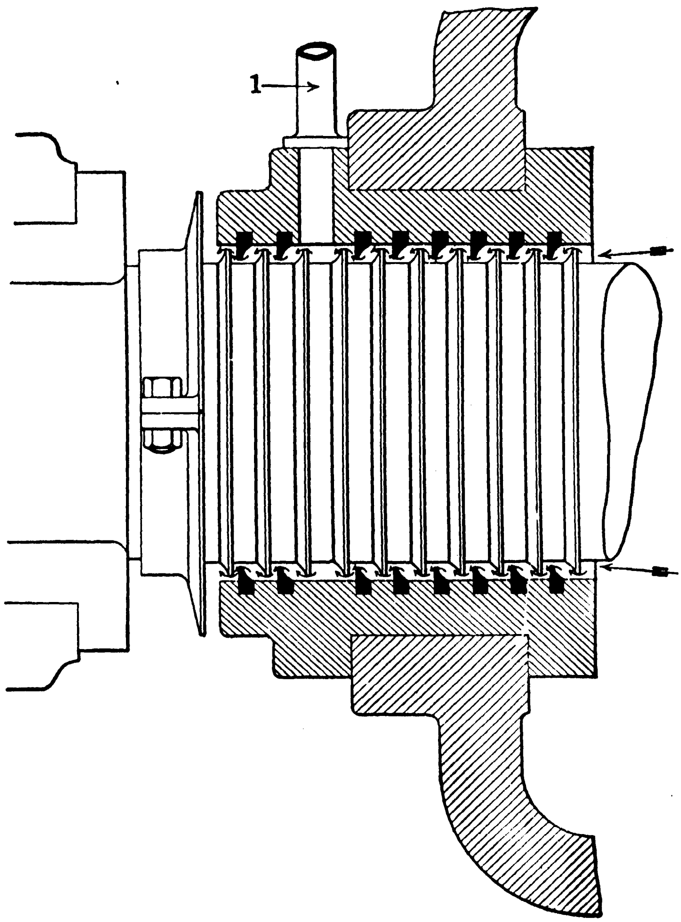


FIG. 68.—Labyrinth packing.

The pressure should be sufficient to prevent air from leaking in; *i.e.*, sufficient pressure should be applied so that a puff of steam is just visible oozing out of the gland. Excessive pressure should be avoided, as it means not only waste of steam but also excessive condensation of steam on the shaft with a certainty of some of this getting into the bearings. Avoiding excessive condensation is particularly difficult in the case of the low-pressure glands of exhaust-steam turbines with labyrinth packing glands. Owing to the variation in steam pressure, it becomes

necessary for the attendant constantly to readjust the gland pressure; otherwise, either air will occasionally leak inward, or excessive leakage of steam will take place outward. Occasionally the glands are water cooled, as the steam then condenses on its way through the gland, and consequently the thrower outside the gland has to deal only with water, which can be much more effectively thrown away from the shaft than steam.

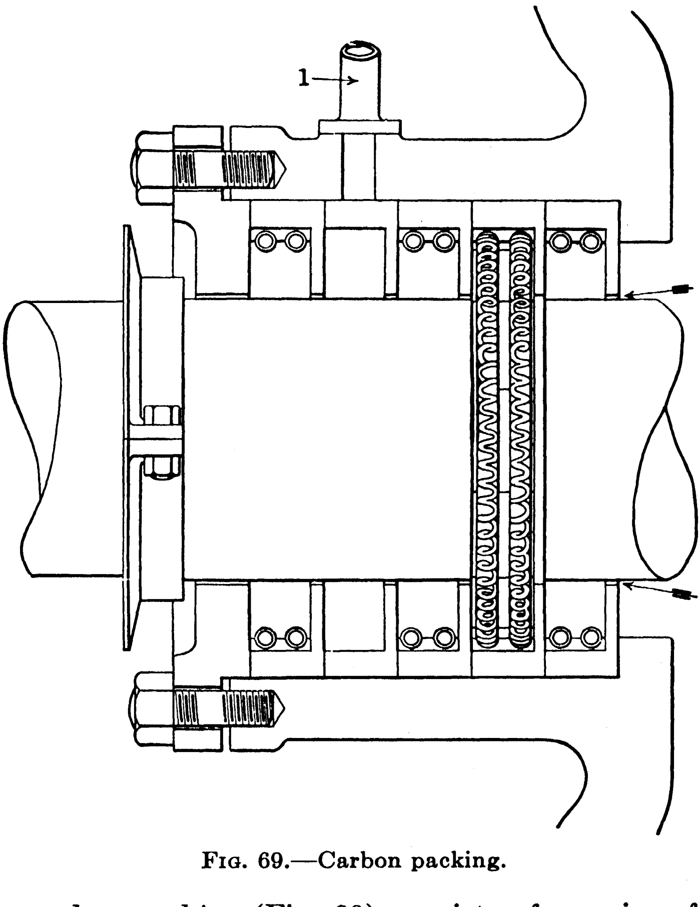


Fig. 69.—Carbon packing.

2. The *carbon packing* (Fig. 69) consists of a series of carbon rings, each made up of several sections and held in their places around the shaft by means of springs. The carbon rings should preferably not bear right against the shaft but on a special sleeve fixed on the turbine rotor and slightly larger in bore than the turbine shaft, so that, should heavy wear take place, the shaft will remain unhurt, and only the sleeve or the packing itself will get worn. No lubrication is needed of the carbon rings, but care

should be taken that they be a loose fit on the cold shaft, as carbon *contracts* when heated. If grit and dirt get in, cutting and wear may occur owing to the absence of lubricant, and then leakage through the packing will take place. Sometimes the carbon packing glands are surrounded with a water jacket, which causes a certain amount of steam to condense in the packing; this helps to seal the gland and "lubricate" the carbons. The vent (1) serves the same purpose as in Fig. 68.

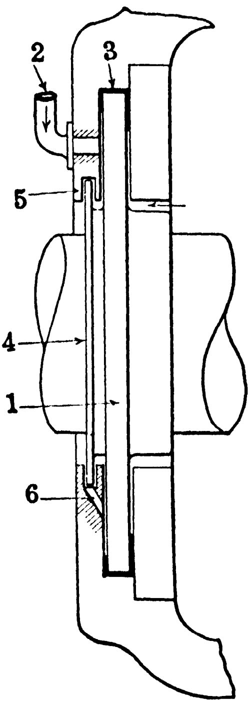


FIG. 70.—Water-sealed gland.

3. The *water-sealed gland* (see Fig. 70) consists of a revolving wheel (1) formed with vanes on both sides and acting like a centrifugal pump. The water admitted at (2) (or sometimes at the circumference at (3) under a few pounds pressure) is thrown by centrifugal action to the outer edge of (1) and thus establishes a perfect seal, it being impossible for steam to escape round the outer edge, the clearance being about 0.01 to 0.02 in. The water should be clean and preferably soft, as otherwise dirt or scale will be deposited in the gland and may even get inside and coat some of the turbine blades. The water supply should be kept as low as possible by regulating the quantity admitted. The second disk (4) revolving in the groove (5) acts as another seal in series with (1), but the chief object in fitting it is to prevent water from escaping from the gland past the groove (5). The water coming into this groove will be drained back into the main gland through drain holes (6) indicated at the bottom.

During the time the turbine is being warmed up prior to starting, and where water-sealed glands are employed, the vacuum cannot be created until the turbine has attained a certain speed, as the glands do not provide a perfect seal until the centrifugal force is sufficient to prevent the air from going straight into the turbine. In case of high-pressure water-sealed glands, it is frequently desirable or necessary to water cool the gland casing, as it otherwise becomes so warm that the water evaporates too readily and gets into the turbine in the form of steam; and, also,

should the water not be very soft, a certain amount of scale will be deposited, which is objectionable. It is only at low speeds—starting and stopping—that the high-pressure water-sealed glands allow steam to escape, thus making it possible for condensed steam to enter the bearing nearest the gland and mix with the oil in circulation.

GEARED TURBINES

The idea of the geared turbine of large horsepower is to run the turbine at high speed, transmitting the power through double helical gearing to a low-speed propeller shaft—or generator shaft—thereby getting a very high over-all efficiency. The gears, when not very accurately made, are noisy and inclined to wear, but the latest developments seem to be overcoming all obstacles in this direction.

If the gears are perfect, and as long as they remain so, the oil used in the turbine can also be used for them, being constantly supplied in streams at the points of contact between the teeth. But if the gears are inclined to be noisy, a heavier oil will be preferable in order to deaden the noise. Such a heavy oil will not be satisfactory in the turbine system, as it will separate only slowly from water and dirt and cause high temperatures all around.

If one oil system only is used for turbine bearings and gearing, and if the oil gets mixed with water—from the glands or the cooler—the oil will suffer in the turbine system to some extent; but when this same oil, mixed with minute particles of water and dirt, gets through the gearing exposed to many times the ordinary bearing pressure, it is sure to suffer very quickly indeed, and the result will be wear of the gearing. For these reasons, the author strongly recommends that the oiling system for the gearing should be made *distinct* and *separate* from the oiling system supplying the turbine bearings, quite apart from the question of whether the same oil or two different oils are used in the two systems. With separate oiling systems, the oil for the gears will remain dry and pure for a much longer time and will thus have a much better chance of keeping the teeth of the gears in good condition and preventing wear.

Treatment of the Oil.—Before starting a new turbine, it should be carefully cleaned all through the oil tanks, oil pipes,

etc., in order to remove as much grit and dirt, molder's sand, rusty scale, cotton waste, etc., as possible. Cotton waste must never be used for cleaning purposes, as it leaves behind small fluffy pieces, which will tend to clog up the oil pipes and particularly the fine clearance spaces in the oil-worked governor.

Mutton cloths or sponges should be used for cleaning, and it is preferable to use a cleaning oil—light petroleum distillate with a higher flash point than paraffin—rather than paraffin, as some of the oil remains and mixes with the lubricating oil. Paraffin will start to evaporate when the turbine starts running and may cause an explosion. The air should be driven out of the oil piping by means of the auxiliary oil pump, and when the pump is being filled with oil it should be put through the sieve and not direct into the tank, although the latter may be the quicker method.

After a new turbine has been run a month, during which time frequent examinations of the oil strainer will prove of interest, the whole charge of oil should be removed, and the oil tank and oil pipes, as well as the bearings, again thoroughly cleaned. The oil taken out, in which will be found impurities of many kinds, such as cotton waste, rust, sand, dirt, little pieces of iron, copper, red lead, and packing material, should be treated in a steam-heated separating tank and afterward in a good steam-heated filter or a centrifugal oil purifier. It can then, if it was originally of good quality, be used as "make-up" in the circulation system, which in the meantime has been filled with a fresh charge of oil. This first change of oil may seem an unnecessary precaution to take, but it is the author's strong recommendation, based on long experience, that it should always be made and that it pays in the long run.

It is during the early life of a turbine that it needs the greatest amount of care and attention; later on, troubles are or ought to be rare if the oil is well looked after, frequently filtered, and the strainers kept clean. As regards the inside of the turbine oil chambers, etc., the surfaces have by some makers been painted; this has sometimes been done in order to save the labor of cleaning and scraping the surfaces. In nine out of ten cases the paint itself has been by no means oilproof, and the result has been that the warm oil quickly dissolved it, causing long protracted troubles with the oil breaking down and carrying

sticky brownish-black deposits everywhere throughout the oil system. The writer recommends leaving the tanks, etc., unpainted but that the surfaces should be very carefully scraped and cleaned. Sandblasting appears to be too "searching," small grains of sand being embedded in the cast-iron surfaces and involving a possibility of trouble later on. Steel-shot blasting is a very efficient method of cleaning the surface.

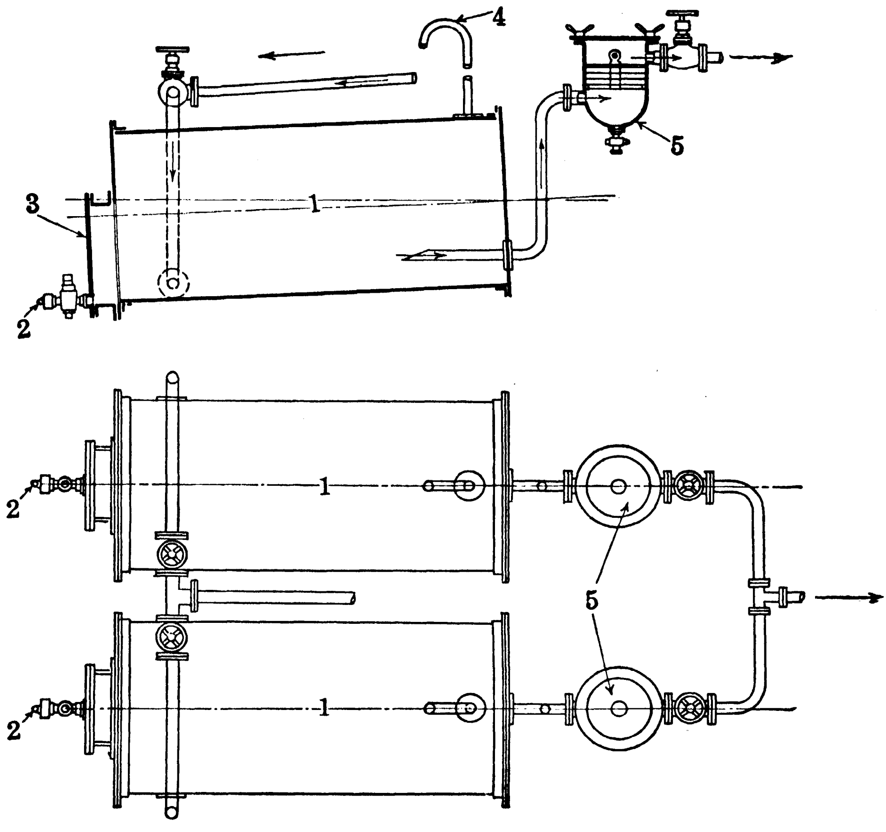


FIG. 71.—Two-tank system.

Oil Filters and Settling Tanks.—When a turbine is in normal operation and has been thoroughly cleaned, the amount of impurities that get mixed with the oil is usually small, and as far as the oil-circulation system itself is concerned, the only precautions as regards filtering may be confined to a good sieve in the oil-return tank, a cylindrical strainer on the pump suction pipe, or a set of gauze strainers. Ample capacity of the oil tanks is always a desirable feature, leading to longer life of the oil and also giving the impurities and water a chance to separate out.

A special design of separating tanks, under the name of the "two-tank system," is used in a great many turbine ships (see Fig. 71).

The two tanks (1) shown are not intended to be used concurrently. The oil is allowed to rest in one of them for a certain period, while the oil circulation takes place through the other. When the oil has "rested" a sufficient length of time to ensure complete separation from water and other impurities, the large drain cock (2) placed at the lowest part of the tank is opened, and the water, dirt, and sludge are drained away until pure oil appears. Means should be provided to show clearly the amount of water in the oil, and for this purpose a glass-sided box (3) is placed at one end of the tank in preference to the ordinary gauge glass; a strip of 1/8-in. steel plate should be placed at the ends of the box to slide in a groove, the idea being to prevent breakages of the glass and, by lifting the steel sheet, to enable one to see the amount of water separated out. An air pipe (4), as shown in the drawing, should be fitted to the highest point of the tank and led to the necessary height. The oil passes a filter (5) on its way to the oil pump.

In cases where a large proportion of water finds its way into the oil, a heater might be fitted in the return pipe to raise the temperature of the oil to about 150°F. This will result in immediate separation of all water and foreign matter as soon as the oil enters the suction tank, the oil rising quickly to the top, and the separated matter remaining at the bottom. To facilitate separation, the return pipe should go almost to the bottom of the tank and deliver the oil in a downward direction. The tanks should be tilted; the suction of the pump should be placed as high as possible, the opening of the pipe to be directed upward if possible. The net storage capacity of the tank is, of course, the capacity above this level. On leaving the tank the oil is sucked through a filter consisting of three or four separate layers of gauze of, say, 24 mesh to the inch, the uppermost layer consisting of two sheets of gauze with a sheet of cheesecloth between them. The bottom of the filter forms a convenient receptacle for any dirt that may have been carried as far as this point, the dirt dropping downward from the filter gauze.

In small and medium-size turbine plants ashore, where, as a rule, each turbine has its own separate oiling system, the two-

tank system has only rarely been employed. The oil circulates continuously and gets little rest when the turbine is in operation. In such plants it is good practice to remove daily from 3 to 6 gal. of oil from each turbine unit, treating this oil in a steam-heated separating tank and filter. The purified oil should be returned to the circulation system at the same time that a corresponding quantity is drawn off for treatment. In this way the vitality of the oil can be maintained at a high standard. If the oil-tank capacity is small, it is particularly desirable to follow this practice.

In large turbine power stations consisting of several units it is often desirable to have a separate plant for supplying the oil to the various turbines and for cooling and purifying the return oil. There are several designs of such plants, but common to them all is the feature that a portion of the oil is by-passed through a filter, while the main flow of oil is only strained and cooled, not filtered. The oil coolers, oil filters, and oil tanks are all made up from several identical units, so that the necessary cleaning and inspection can be made while the plant is in operation and without disturbing the normal operation of the oil plant.

Centrifugal Purification.—The best and most efficient method of cleaning turbine oil is, however, by centrifugal purification. (For description of the purifier see page 598.)

The *purifier* protects steam turbines automatically and continuously, removing all water and impurities from the oil in circulation; it maintains the lubricating and cooling properties of the oil almost indefinitely and ensures maximum efficiency of the oil cooler by keeping the tubes free from deposit and sludge.

Keeping the oil dry and free from metallic impurities is obviously of the very greatest importance, and particularly so in connection with geared turbines, in which the problem of how to avoid wear of the gears is still a troublesome one.

The centrifugal purifier also helps to keep the contents of petroleum acids at a low figure, especially if hot water of condensation is added to the oil entering the purifier.

This washing of the oil is also beneficial if, as is sometimes the case, sea water enters the oil.

The purifier is preferably installed so that from 5 to 10 per cent of the actual flow of oil through the lubricating system is

by-passed through the purifier, the impurities being continuously removed.

Oil Consumption.—The make-up for lost oil due to leakage and atomization—there is very little evaporation—amounts to from 1 pt. to 4 gal. per week per turbine unit, depending upon the size and operating conditions. The average make-up for a 1,000-kw. turbine is about 1 to 1½ gal. per week.

Acquired Impurities.—During the passage of the oil through the entire circulation system it picks up more or less water, air, iron oxides, and other impurities and, when passing through the main bearings, gets intimately churned together with these foreign matters; the result is that, owing to the high temperature and the great surface speed of the revolving shaft, the oil gradually breaks down.

When ordinary oils, not specially manufactured for turbine use, are employed they may not have a life of more than a few months, whereas high-quality turbine oil may last under normal conditions 10,000 working hours or more and 3,000 working hours under very unfavorable conditions; also, the margin of safety will be considerably greater when using the best possible oils. Whereas all oils, even the best, are affected in time, unsuitable oils will sooner show the signs of breaking down, which are (1) darkening in color, (2) increased specific gravity, (3) increased viscosity, (4) increased acidity, and (5) the throwing down of various kinds of deposits.

The first three effects cannot be said to be detrimental except that they are the "signs of warning" that the oil is breaking down. As regards the acidity, the acid produced in the oil is the result of oxidation and is a petroleum acid which must not be confused with sulphuric acid, which is sometimes found in mineral oils that have been treated with this acid during their manufacture. Petroleum acids do not attack the metals ordinarily used in the construction of the circulation system, but they do slowly dissolve zinc or alloys consisting largely of that metal. Increased acidity can always be taken as a guide to judge how far the oil has suffered, and when it gets in the neighborhood of 0.3 per cent in terms of SO_3, steps should be taken to prevent this limit's being exceeded, by renewing either part of the oil or all of it, as the circumstances may seem to justify. When the acidity of an oil is below 0.03 per cent it is generally considered by chemists

to be "free from acid"; good turbine oils often contain less than 0.008 per cent of acidity when new.

DEPOSITS

Deposits may form even where the best oils are in use, although always in very much smaller quantities than where unsuitable oils are employed. Naturally, it is the constant aim and endeavor of the oil manufacturer to produce oils that possess as great a resistance as possible against the oxidizing and emulsifying effect of the impurities, etc.

The principal causes of deposit, apart from the quality of the oil, are

1. Water.
2. Solid impurities.
3. Air.
4. Electric action.
5. Adding new oil.

1. Water.—Water has an emulsifying effect on the oil, particularly if it contains impurities, whether in solution or in suspension. Where considerable quantities of water leak into the system, and emulsification takes place, the oil becomes yellow or brownish yellow in color; and if a sample is taken out and heated, it will separate into clean oil at the top, more or less milky water at the bottom, and a spongy sludge separating the oil and water. If the oil and the water are removed, the spongy emulsion, which varies in color from gray to brown, will be found to contain from 15 to 35 per cent of oil and to consist of numerous exceedingly thin films of oxidized matter surrounding small drops of water; in fact, the sludge when freed from oil consists of about 99 per cent water by weight and 1 per cent of exceedingly thin films. On analysis these films have been found to be composed of a chemical combination of petroleum acids, produced by decomposition of the oil, and rust (iron oxides), which is found throughout the system.

The nature of the sludge in the oil produced by the water is most objectionable, as it tends to clog the oil strainers, oil inlets to the bearings, and oil inlet to the governor. Furthermore, the oil pressure may be reduced, owing to the oil pump's not delivering the requisite quantity of oil because of the partial choking of the pump strainers. The chief source of water's getting into the

oil is usually the gland packings; water may also leak into the oil in the oil cooler or in the bearings (when water cooled). On sea-going ships a leakage of cooling water into the oil can be detected at once by taste, the cooling water being salt. If one could always be sure of the steam passing the glands producing an absolute soft water of condensation free from boiler salts, it would be an easy matter by analysis to determine whether the water leaking into the oil was from the glands or from the cooler or partly from one, partly from the other source. But when the boilers prime, such analysis becomes almost useless, for obvious reasons. Determining the degree of hardness of the water drawn away from the oil in the system is quite misleading, as the acidity of the water—washed out of the oil—upsets the titration test. Evaporating the water to dryness, ignoring the percentage of metallic salts—iron, copper, etc.—that the water has dissolved from the oil pipes, and comparing the grains of salts remaining with the results when evaporating a similar volume of cooling water are about the only reasonably accurate chemical method of forming an idea as to where the leakage occurs.

Mechanically, it is often possible—sometimes even quite easy—to locate the leakage.

Where leakage of water into the oil system cannot very well be avoided, a "water leg" consisting of at least 4 ft. of vertical pipe—2½ to 4 in. in diameter—fitted to the bottom of one of the oil tanks may do great service, as it will catch the fine drops or particles of water circulating with the oil; and once a particle is caught in the leg it cannot again rise and mix with the oil; it goes to the bottom of the leg, which should be drained twice every 24 hr. Strict instructions should be given that the drain cocks in the oil tank or tanks should be opened twice every 24 hr. and every time the turbine is about to start up after a rest; the drains should be kept open until clean oil appears.

Turbine oils are affected by water if it contains boiler salts in solution, more than by clean water, and certain boiler compounds have a strong emulsifying effect, but the greatest effect seems to be produced by iron salts in solution. The water cannot help dissolving some of the iron during its rapid flow through the oil pipes, hence the desirability of using copper oil pipes in preference to iron pipes; copper is little attacked by water, and a copper

solution has only a slight emulsifying effect on the oil as compared with the effect of an iron solution.

2. Solid Impurities.—The disintegrating effect on the oil caused by finely suspended solid impurities, such as fine rust and molder's sand, is very marked. The oil darkens considerably in color; the acidity increases rapidly; the oil assumes a "burnt" odor; a slimy dark-colored deposit develops and lodges particularly in the oil cooler. If, furthermore, there is a leakage, however slight, of water into the oil system, the oil may get badly emulsified, much more than would be the case with water alone, as the oil is in a weakened condition due to the oxidizing effect of the solid impurities. This will explain why, when a new turbine is being started up for the first time, emulsification of the oil may occur even if the oil is of good quality.

Where the inside of the oil tank is painted, emulsification and breakdown of the oil usually occur, as there exist hardly any paints that are "oilproof" under the exacting conditions prevailing in turbine practice. The advisability of changing the initial charge of oil will, in view of what is said above, now be fully understood, the effect being that the entire system gets thoroughly cleaned and that the fresh charge of oil will have very much better conditions to work under.

3. Air.—The circulating oil always contains more or less air; and when the temperature is above normal, say more than 140°F., this air has a tendency to oxidize the oil, a tendency that increases rapidly with increasing temperatures. This effect will be better realized when one considers that the oil film in the bearings is very thin and that the air is present in exceedingly fine bubbles, which are intimately mixed with the oil. The result is that the oil darkens in color, increases in acidity, and in extreme cases a black, carbonaceous deposit develops, which is exceedingly dangerous, as it may choke the oil inlets to the bearings and cause sluggish working of the governor gear or may even cause it to stick, putting the governor out of action.

Another effect of air in the oil shows itself only when an abnormal amount is present; the effect is known as "fuming." Fumes issue from the main bearings and oil tank, notwithstanding that the bearing temperatures are quite normal; the fumes may be drawn into the generator windings and cause disastrous results. The cause of the "fumes" is that the fine air bubbles, with which

the oil is heavily charged, burst in the bearing cavities and in the oil tank, producing a very fine spray of oil which oozes out in the form of a mist—the oil "fumes." The oil will be found creeping all over the outside of the bearings and turbine bedplate, forming a very thin film, and the loss of oil may be quite considerable—several gallons per 24 hr. The remedy is to prevent, as far as possible, the oil from getting churned together with the air. Perhaps the churning takes place between oil throwers and baffle plates inside the bearings, or the oil gets violently disturbed in the sight-feed arrangements in the return pipes or where the return branch pipes join the main return pipe, etc. If the spray is formed inside the bearings, these should be ventilated, a large pipe connection being taken from the air space in the bearing cavities to the oil-return tank. The fumes will then go through these pipes instead of oozing out of the bearing ends; sometimes enlarging the oil-return pipes will overcome the trouble. The main return-oil tank should always have a vent pipe, at least 1 in. in diameter, to prevent accumulation of oil fumes in this tank and in the return-oil pipes. Frothing may also occur temporarily when a considerable percentage, say 50 per cent, of the oil in circulation is renewed at one time. New oil should always be added in small quantities at a time.

4. **Electric Action.**—If in the case of the electric generator there is a slight leakage of electric current from the generator (direct-current generator), or if the magnetic field is out of balance (alternating-current generator) and produces induced currents in the turbine shaft, the result is that an electric current passes through the shaft down through one of the main bearings, through the bedplate, and up through another main bearing back into the shaft. The effect on the oil is that it quickly darkens in color, increases in acidity, and throws down a deposit which coats all parts of the turbine with which it comes in contact, lodging particularly in the oil cooler. The deposit is of a fairly hard, brittle nature and of dark chocolate color; it is exceedingly difficult to remove and therefore very objectionable. The remedy is completely to insulate electrically one of the main bearings from the turbine bedplate, including the connections between the oil pipes and that particular bearing. This insulation will prevent the formation of an electrical current, and consequently the formation of deposits will cease.

On rare occasions local galvanic currents may cause corrosion of the oil tubes in the oil cooler or of the turbine shaft and bearings and even in the governor, causing the oil-operated piston to stick, or may eat away the sharp edges of the pilot valve.

5. Adding New Oil.—Where practically no water enters the circulation system, and where practically no waste or leakage of oil occurs, so that the amount of new oil added to the system per week is only very small, the oil in time becomes very dark in color, and the acidity increases considerably. In such cases it has been found that when new oil is added a dark deposit is thrown down throughout the system, owing to the action of the old oil on the new, and this is particularly the case with heavy-viscosity oils rather than with light oils.

Speaking generally, deposits are always inclined to accumulate in the most dangerous places, such as the oil pipes leading from the main oil pipe into the main bearings. A partial choking of the oil inlet would reduce the oil feed; the bearing would heat up quickly; and if not observed in time the bearing surfaces would with all certainty be destroyed, which might have very serious consequences, owing to the high speed at which all turbines operate and particularly so on account of the time that it takes—half an hour or more—for the turbine to come to rest from full speed. If deposits get into the oil pipe feeding the governor gear, the governor may fail to act, and consequently the turbine would either gradually slow down or increase in speed much above the normal speed. The parts inside the governor gear in contact with the oil are very sensitive—with small clearances—and the oil must be absolutely clean and good in order to make the parts work smoothly.

Typical Examples of Turbine Troubles

Example 1: 1,000-*kw. Turbine,* 3,000 *r.p.m.*

Temperature of oil leaving bearings	120°F.
Temperature of oil leaving cooler	110°F.
Quantity of oil in circulation	60 gal.

The oil cooler contained 100 copper pipes 21 mm. in diameter and 1 m. long, the oil being sucked from the cooler, with the result that a slight amount of water was always leaking into the oil in the cooler owing to the thin copper tubes' not keeping quite watertight in the end plates. The cooling water was taken from

a brook; it was practically soft water, and for several years no trouble had been experienced. The oil in use was similar to circulation oil 1 (page 408) and gave complete satisfaction. Suddenly trouble began. An emulsified sludge was formed throughout the oil system, and the bearing temperatures increased. It was found necessary to change the oil every 3 to 4 weeks, whereas previously the oil (without any daily treatment) was renewed only every 6 months.

A thorough examination revealed the fact that the oil cooler was leaking and furthermore that the water supply had been changed. The water instead of being taken from the brook was taken from the coal-washing plant, after indifferent filtration; it contained coal dust and was exceptionally hard. An emulsification test with fresh oil, using this water, showed unsatisfactory separation and explained the cause of the trouble.

As a result of the higher bearing temperatures which had prevailed for several months a large amount of sludge had settled in the oil cooler and gradually baked into a fairly hard deposit which almost choked the cooler.

Example 2: 3,000-*kw. Turbogenerator.*

Oil temperature of bearings............	120 to 130°F.
Quantity of oil in circulation...........	120 gal.
Rate of circulation.....................	Exceptionally rapid

A certain amount of sludge was continuously developed in the oil system and settled at the bottom of the turbine-bed chamber in the form of an oily sludge. Two samples were drawn at an interval of 7 weeks and analyzed as shown in table on page 231.

It will be seen that the color of the oil, which when the oil is new is about 35, has darkened considerably, also that the acidity of the oil and sludge has increased between the dates of taking the two samples. The cause of the deposit is emulsification and oxidation of the oil, brought about by the rapid circulation (aeration of the oil) and also the very small volume of oil in circulation. Only a small amount of water was leaking into the system, but owing to the very rapid circulation of the oil the water was never given a chance to separate out.

Example 3.—Four large turbines were using an exceptionally heavy turbine oil similar to circulation oil 3. The bearing temperatures were high—from 150 to 165°F.—and the oil coolers

were constantly filling up with a thick sludge. An investigation proved that the boilers were priming. The boiler salts carried over with the steam found their way through the turbine glands into the bearings, contaminating the oil and causing the sludge. Owing to the fact that the oil was far too viscous for the conditions, the cumulative effect of the water charged with boiler salts was very troublesome.

A change in grade of oil to a light-viscosity oil similar to circulation oil 1 was made, with the result that the bearing

Oily sludge and its contents of sludge and oil	Sample 1, per cent	Sample 2, per cent
Oily sludge:		
Oil	12	17
Water	22	36
Sludge	66	47
Sludge:		
Water	45.1	43.0
Oil	34.2	34.2
Volatile matter insoluble in petroleum spirit	18.5	20.0
Ash (containing oxides of iron, silica, and lead)	2.2	2.8
Petroleum acids	1.389 as SO_3	1.598 as SO_3
Oil:		
Acidity	0.154	0.218
Color, Lovibond ¼ in. cell	125	179

temperatures were reduced to 120 to 130°F.; and at the same time an efficient system of daily treatment of the oil in the turbine was instituted. It was then found that very little sludge formed in the system and that the little that did form was largely removed from the oil by the process of daily treatment.

Example 4.—That an admixture of fixed oil, whether vegetable or animal, quickly causes trouble when water is present is obvious and usually very soon detected. The following example is of interest in this connection.

A new grade of turbine oil was tried on board a large turbine steamer, the entire system being cleaned out and filled with it. On the first trip the new oil became badly emulsified, and the chief engineer, complaining bitterly, insisted upon reverting to the old. Careful examination proved, however, that there was

a small percentage of saponifiable matter present in the turbine system and in the turbine oil-supply tanks on board the boat; and strangely enough the percentage of saponifiable matter, although very small, was greater in the oil circulating in the turbine than in the oil in the supply tanks. It was evident that some compounded marine-engine oil had been "accidentally" added to the system, and evidently a slightly greater proportion had been added to the turbine system than to the supply tanks.

In connection with marine steam turbines great care must be exercised to prevent contamination with marine-engine oils, which are always compounded with vegetable or animal oils. This point must be particularly watched in case of large warships, where oil is pumped on board through a flexible hose; a separate line must be used for turbine oil.

Example 5.—In a large turbine shortly after erection the bearing temperatures began to rise, and a tenacious emulsified sludge developed throughout the system. It was found that the water-softening plant for treating the boiler water had not been properly looked after, excess soda getting into the boilers. Priming of the boilers carried soda into the turbine, and through the glands it finally reached the oiling system. The turbine-bed chamber was painted with "oilproof" paint, but the soda very soon dissolved or destroyed it, and mixing with the water brought about the emulsification.

Example 6: 3,000-*kw. Turbine.*—An oil similar to circulation oil 1 and of good quality was in use. Oil temperatures were normal, being approximately 120°F. The quantity of oil in circulation was 60 gal.; it was drawn through the cooler by the oil pump, so that it was always under suction. Very little water leaked into the oil system, being approximately 1 pt. per 24 hr.; the oil gave excellent results and was renewed only once a year. A thin deposit having the following composition developed in the oil cooler:

	Per Cent
Oil with a trace of moisture	46.4
Volatile matter insoluble in petroleum spirit	48.9
Fixed carbon and silica	0.1
Iron oxide	2.2
Copper oxide	2.0
Balance undetermined	0.4

A sample of the water leaking into the oil system was analyzed and found to be very hard, similar to the cooling water. Obviously, the cooling water had constantly leaked into the oil system; owing to the small volume of oil in rapid circulation, considerable aeration took place, and the combined effect of the air and water produced slowly the deposit that was found in the oil cooler.

This and Example 1 point to the desirability of always having the oil under a pressure in the oil cooler higher than the pressure of the cooling water.

Example 7.—A 1,500-kw. turbine had for several years been using an oil similar to circulation oil 1 with every satisfaction.

Quantity of oil in circulation	80 gal.
Bearing temperatures	Quite normal

Suddenly the bearing temperature rose within one week from about 110 to 140°F. On examination it was found that a thick deposit had developed and nearly choked the oil coolers. The deposit on analysis gave the following composition:

	Per Cent
Oil and water	42.8
Volatile matter insoluble in petroleum spirit	17.8
Fixed carbon and silica	1.6
Iron oxide	36.4
Balance undetermined, containing copper oxide, etc.	1.4

Analysis of the oil showed that it was in very good condition, the percentage of petroleum acids being only 0.05 per cent. It was somewhat dark in color and heavier in viscosity than the fresh oil but nothing to be alarmed about.

On the oil pipes' being taken apart it was found that during 5 years' operation the pipes had rusted on the inside, and a portion of the rust had been either absorbed by the water circulating with the oil or circulated in the form of a fine powder.

As mentioned elsewhere, finely divided iron and iron salts have a powerful effect on turbine oils. This explains the formation of the sludge which almost put the oil coolers out of action and brought about the high bearing temperatures.

Example 8: 1,700-*kw. Turbogenerator*, 3,000 *r.p.m.*

Quantity of oil in circulation	60 gal.
Temperature of oil leaving bearings	Approximately 150°F.
Temperature of oil leaving cooler	140°F.

Great trouble was experienced in this turbine with oxidation. A black brittle deposit developed throughout the system, settling particularly in the oil cooler and in the oil inlets to the bearings, also in the governor gear, preventing the governor from functioning properly.

	Unused	Used
Oil:		
Specific gravity, Open flash point, Fire point: Unaltered		
Saybolt viscosity at 104°F., seconds	135	153
Color	40	400
Petroleum acids as SO_3, per cent	0.006	0.08
Deposit:		
Volatile matter insoluble in petroleum spirit, per cent	.....	95.2
Ash, chiefly iron oxide, per cent	.....	4.8

The analysis given in the preceeding table compares the unused oil and the oil after 4 months' use.

It is obvious that the temperature of the oil in circulation was too high and the amount in circulation too small, with the result that the oil was quickly oxidized.

Example 9.—A large turbine suddenly developed high bearing temperatures, and an investigation proved that the vertical oil cooler had become air locked, the upper part of the oil cooler thus being put out of action. The obvious remedy was to fit an air-vent pipe, leading the air from the uppermost part of the oil cooler up to the main oil-return tank.

Example 10.—A 1,000-kw. steam turbine immediately after erection was greatly troubled with oil vapors oozing out of the turbine bedplate (used as the oil reservoir), which meant not only a large waste of oil but also a considerable danger to the generator.

An investigation proved that the oil-return pipes from the bearings, instead of sloping gradually into the bedplate, were vertical; the return oil falling into the reservoir caused the oil to splash about and form a great deal of oil spray. The return-oil pipes were then altered, and the trouble ceased.

Example 11.—A 1,500-kw. steam turbine was greatly troubled with oil vapors which evidently emanated from the main bearings,

and the presence of oil in the generator was clearly visible. Everything possible had been tried to stop the vapors emanating from the bearings, when on an investigation by an oil expert it was found that the return-oil tank had no vent pipe and that the fine oil spray developed in the bearings could not pass back into the oil tank but simply filled up the oil-return pipes and then had to find its way out through the bearing ends. The obvious remedy was applied, and the trouble thus overcome.

Example 12.—A 1,500-kw. Howden turbine, 3,000 r.p.m., was using an oil similar to circulation oil 2 and of good quality. Difficulties were experienced with the oil's "creeping" along the turbine shaft and getting into the generator.

An investigation proved that the oil was unnecessarily viscous for the conditions, and an oil similar to circulation oil 1 was installed to see whether the change would make any difference. Curiously enough, the creeping of the oil entirely disappeared without the engineer's being able to offer any definite explanation as to the reason why it ceased. At the same time, a remarkable difference in the bearing temperatures took place, as shown in the following table:

	Oil, °F.	
	Old	New
Bearing 1	130	116
Bearing 2	124	110
Bearing 3	122	108
Bearing 4	123	108
Bearing 5	134	122
Bearing 6	116	106
Temperature of inlet oil	110	98
Temperature of outlet oil	130	114
Temperature of inlet cooling water	48	48
Temperature of outlet cooling water	78	68
Temperature of engine room	80	79

The foregoing figures show clearly the lower bearing temperatures obtained by using the low-viscosity oil, notwithstanding that the supply of town water through the oil cooler was greatly decreased when the new oil had been installed; as town water had

to be paid for, the change in oil brought about a quite considerable saving in the water bill.

Note.—Where oxidation takes place owing to oil temperatures' being too high, a change to lighter viscosity oil has often reduced temperatures and stopped the oxidation.

Example 13: 350-*kw. Mixed-pressure Turbine*, 3,000 *r.p.m.*

Temperature of oil leaving bearings	120°F.
Temperature of oil leaving cooler	105°F.
Quantity of oil in circulation	60 gal.
Oil consumption	1 gal. per week added to the system

The turbine was in operation day and night continuously until it had to be stopped owing to the breaking down of the armature of the generator. Before the turbine was stopped the oil temperatures had for several weeks been gradually creeping up, for some unknown reason. When the turbine was opened up for inspection the flexible coupling between the turbine and the generator was discovered to be absolutely solid with a black brittle carbonaceous deposit, which was also found throughout the entire oil system.

Strangely enough, there was no perceptible wear of any of the bearings; the surfaces of the brasses were black and dull, covered with a very slight deposit. The oil from the turbine had a charred odor and a dark-brown bloom, whereas the bloom of the fresh oil was green. It was apparent that a radical change had taken place in the oil. The deposit consisted of

	Per Cent
Oil and volatile matter insoluble in petroleum spirit, with a slight percentage of water	77.4
Fixed carbon	2.4
Iron oxide	10.5
Copper oxide	8.4
Undetermined, containing carbonate of magnesium, traces of lead, etc	1.3

The total amount of the deposit was about 25 lb., and a large portion of this had undoubtedly been in constant circulation with the oil in the form of very fine powder which settled when the turbine was stopped. Owing to a fault in the rotor and armature, stray currents had passed down through the bearings, oil pipes,

oil cooler, etc., and had caused the oil to break down, developing the deposit.

The remedy, apart from putting the rotor in order, was to insulate the end bearing of the turbine entirely from the bedplate. This practice is now followed by a good many turbine builders.

Example 14.—A 1,000-kw. exhaust steam turbogenerator had an electric breakdown similar to that of the turbine mentioned in Example 13. The oil used underwent a remarkable change in the course of one week, becoming changed in color from 35 to 180 and the acidity increasing from 0.002 to 0.298 per cent; simultaneously, the viscosity increased about 20 per cent. A brownish brittle deposit with a lustrous fracture developed throughout this system and had the following composition:

	Per Cent
Water	24.2
Oil	17.2
Volatile matter insoluble in petroleum spirit	52.0
Ash, chiefly iron oxides	4.3
Petroleum acids	2.3 as SO_3

CURTISS VERTICAL TURBINES

These turbines are found chiefly in the United States, only a few having been installed in England. They operate electric generators and are made in sizes from 500 to 20,000 kw., the corresponding speeds ranging from 800 down to 720 r.p.m. The revolving parts are supported by a combined step-and-guide bearing and by upper and middle guide bearings. The middle bearing may be left out with smaller machines where the turbine shaft is in one piece.

The step bearing is shown in Fig. 72 and consists of two cast-iron blocks, one carried by the end of the shaft, and the other held firmly in a horizontal position and so arranged that it can be adjusted up and down by a powerful screw. The lower block is recessed to about half its diameter, and into this recess oil is forced with sufficient pressure to balance the weight of the whole revolving element; there are, of course, no oil grooves. The amount of oil required is small—from 1½ gal. per min. for a 500-kw. machine to about 6 gal. per min. for an 8,000-kw. machine. The oil, after passing between the blocks of the step bearing, wells upward, lubricates a guide bearing supported by the same casting, and leaves through oil drain (1).

A carbon packing, prevented from rotation and consisting of two sections of rings, each section comprising two rings made up from three segments, is fitted above the oil thrower (2), and, in order that no oil or air shall enter the turbine chamber above the packing, a low steam pressure is maintained between the two sections of the packing, just sufficient so that vapor is visible

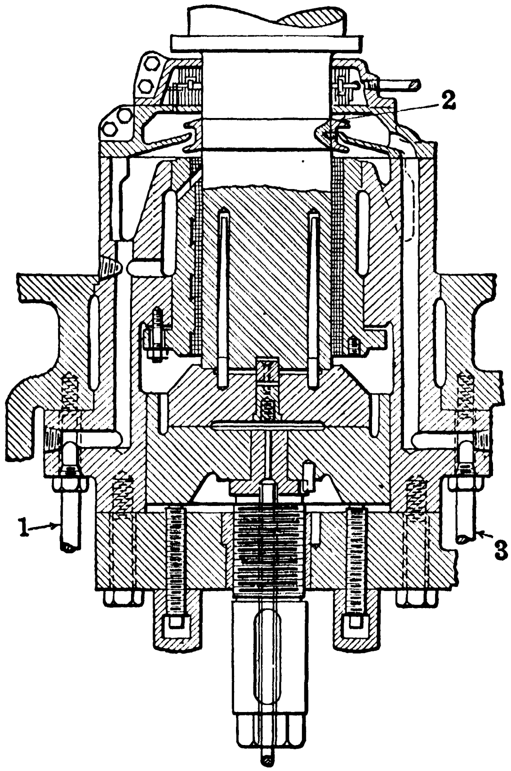


FIG. 72.—Curtiss step bearing.

at the outlet of the drain pipe (3). If the flow of oil into the bearing is too great, the oil overflows into drain (3), mixing with the steam; the mixture should be drained into a separate tank with baffle plates, in which the water is held back; the recovered oil may be allowed to enter the main oil system when entirely freed from water.

The oil pressure required for the step bearing is slightly higher than the bearing pressure, ranging from 300 to 800 lb. per square inch, thus producing perfect oil-film lubrication. To start lubrication a pressure 25 per cent greater than the normal running pres-

sure is needed. The film thickness depends upon the flow of oil, ranging usually from 0.003 to 0.006 in.

In some designs a powerful brake bearing is provided which can be operated from the outside and can be used to take the whole weight of the revolving part in case the step-bearing support should fail. In ordinary operation the shoes of this brake will be set about 0.01 in. below the brake ring. It is thus in a position to receive the revolving part in case the step-bearing support should fail. Another and more important feature of this brake is to stop the machine when it is desired to do so. A 5,000-kw. machine will run for 4 or 5 hr. after the steam has been shut off, unless a brake is applied.

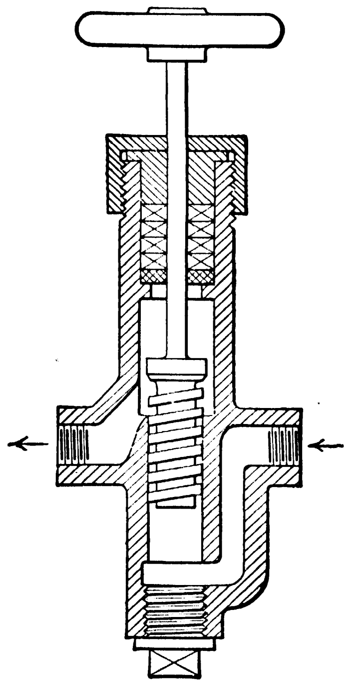


FIG. 73.—Oil pressure baffler.

In some cases the step bearings have been operated with water instead of oil, in which case no packing is necessary, the water being allowed to pass up into the turbine. The trouble with water is that it causes rusting of parts. When accidentally the step-bearing oil pressure has dropped below the pressure required, the bearing surface immediately cuts; but the metal is removed very slowly, and lubrication is easily reestablished when the pressure oil flow is restored. Precautions are, however, taken in the shape of accumulators and other auxiliaries necessary for the maintenance of a flow of pressure oil to the step bearing.

The guide bearings are babbitt-lined sleeves, with a clearance of 0.0005 in. per inch shaft diameter for the lower and twice this clearance in the upper and middle guide bearing. They have suitable oil grooves to ensure good oil distribution; the oil is fed at the rate of 0.5 to 1.5 gal. per min. per bearing according to size and is distributed by gravity from an elevated oil tank or from branch pipes from the main pressure system.

In the latter case, bafflers, as illustrated in Fig. 73, are fitted to reduce the oil pressure. The oil is forced to pass through the narrow spiral passage formed by the thread, and the longer the

passage the more is the pressure reduced. These bafflers are also placed in the delivery line to the step bearing to reduce the

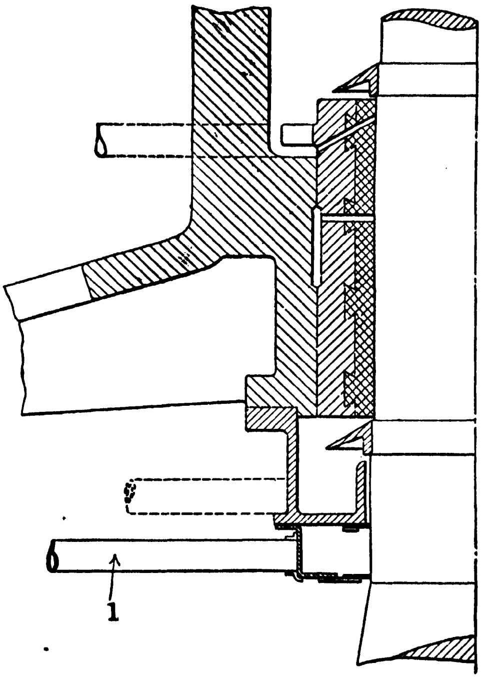


FIG. 74.

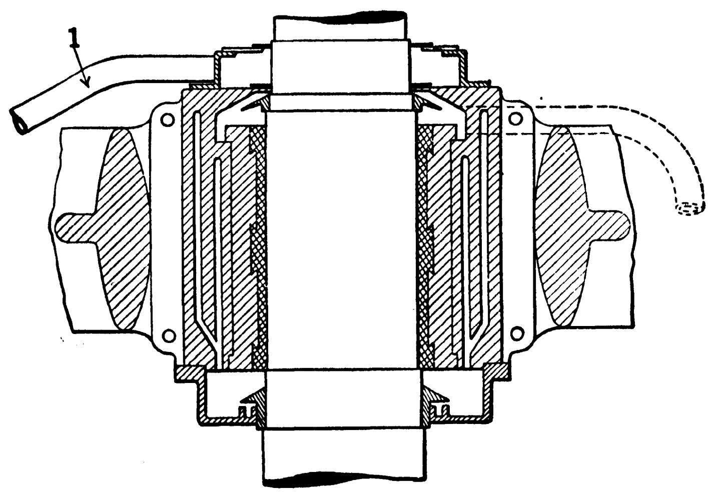


FIG. 75.
FIGS. 74–75.—Preventing oil spray from guide bearings.

pressure and also to reduce the intensity of the pulsations caused by the reciprocating main oil pump. When the oil leaves the

guide bearings it is thrown off into oil troughs, large drain pipes guiding it back into the oil reservoir.

A carbon packing is also fitted between the middle guide bearing and the turbine; excessive steam admitted to this packing will mix with the return oil from the middle guide bearing and should be avoided.

The guide bearings may cause trouble by oil throwing, caused by leaky joints (which is easily remedied) or by oil spray sucked out from the bearings by the draft created by the rotating parts. Deflectors, as shown on page 168, may also be adapted for vertical turbines, but the disease is a troublesome one to cure. Possibly the oil supply is too great, particularly when the oil is introduced under great pressure, or the oil troughs may have become obstructed by dirt, which may account for the oil's getting into the generator; they, as well as the oil-return pipes, should therefore be kept clean. If oil leaks through a porous casting, a mixture of litharge and glycerin applied to the points of leakage is said to be a remedy.

To stop the fine oil spray from being carried out from the bearings, it is necessary to equalize the air pressure outside and within, as shown in Figs. 74 and 75 for an upper and middle guide bearing, respectively. The pipes (1) are pressure-equalizing pipes, taken outside to a point where there is no suction; and, in addition, felt rings are fitted, as shown, and prove very effective as long as they are not worn too much. The arrangements in Figs. 74 and 75 were designed by E. D. Dickinson of the General Electric Company. The casings are made of sheet iron with riveted joints; the felts are fastened by means of metal rings. Where bolts are used they should be locked, so that the nuts cannot come undone through vibration.

Oil Distribution.—The oil is distributed under pressure to the step bearings and guide bearings as described, but the latter are sometimes fed from an elevated tank, with an overflow pipe back to the oil reservoir. On its way to the bearings the oil pressure is reduced by one or more bafflers, so that each bearing gets the right amount of oil. The oil is returned by gravity from the bearings and passes a filtration and cooling system, in which it is freed from water, dirt, and other impurities, before it is circulated afresh.

The oil reservoirs should preferably be in duplicate and operated alternate days.

When water is used for the step bearing, the oil pumps have to supply oil only for the upper and middle bearings, usually by way of an elevated tank. The amount of oil going to each bearing is regulated by small control valves and sight feeds in each line.

In an installation of one or two units of the same capacity, two high-pressure steam-driven pumps supply oil to the step bearings, and two low-pressure pumps supply the upper and middle guide bearings and an accumulator gear, for equalizing variations in pressure caused by fluctuations in the speed of the pumps. These accumulators in case of failure of pump will keep the turbines running for some time and automatically cause reserve oil pumps to come into action. The accumulators may be on the principle of a heavy weight which is raised or lowered according to the amount of oil "stored" in the accumulator. Air chambers have also been used as pressure accumulators and must be absolutely airtight. In installations of three units of the same capacity three high- and three low-pressure pumps are fitted, two sets being sufficient to supply all units.

In a plant comprising two or more units the starting or stopping of a unit means that the amount of oil required is altered; the alteration in oil supply is automatically brought about by influencing the speed of the oil pumps. The latter should run at no greater speed than that required to give the necessary oil supply plus a margin. If the speed is greater, power is wasted, and an excessive oil supply may cause various kinds of trouble, such as oil throwing, oil overflow into packing drain pipe, excessive churning of the oil in the pumps (causing emulsification when water is present), etc.

The number of gallons of oil in circulation is about 10 per cent of the rated kilowatt capacity for turbines of 4,000 kw. or over; 20 per cent for turbines between 2,000 and 4,000 kw.; and a still higher percentage for smaller turbines, being 200 gal. for a 500-kw. unit.

Oil.—The step-bearing lubrication is not dependent upon the viscosity of the oil; the shaft floats on the oil film, whether the oil is thick or thin, simply because the oil is introduced at a sufficiently high pressure. Some "body" is, however, required for lubricating the guide bearings, particularly when there is a tendency to vibration. Very low-viscosity oils were at one time

used for Curtiss turbines, but any leakage is accentuated by their use, and more oil spray may be formed in the bearings. The oil must, of course, be a circulation oil in order to separate well from water and withstand oxidation. Unless the conditions specially call for a more viscous oil, circulation oil 1 should be recommended in all cases.

SELECTION OF TURBINE OILS

For satisfactory lubrication of steam turbines only three oils are required, having approximately the following specifications:

Circulation Oil 1.* Neutral Filtered Oil

Specific gravity	0.870
Flash point open	395°F.
Viscosity	No. 4 (see page 57)
i.e., viscosity in centipoises at 50°C.: 13	
Setting point	20 to 25°F.

Circulation Oil 2.* Mixture of a Neutral Filtered Oil and Filtered Cylinder Stock

Specific gravity	0.875
Flash point open	410°F.
Viscosity	No. 7 (see page 57)
i.e., viscosity in centipoises at 50°C.: 26	
Setting point	35 to 40°F.

Circulation Oil 3.* Mixture of a Neutral Filtered Oil and Filtered Cylinder Stock

Specific gravity	0.880
Flash point open	425°F.
Viscosity	No. 8 or 9 (see page 57)
i.e., viscosity in centipoises at 50°C.: 38 or 56	
Setting point	35 to 40°F.

* All circulation oils must separate rapidly from water, and only a trace of sludge must be produced in the emulsification test.

Lubrication Chart
For Steam Turbines

Land Turbines.—Circulation oil 1 is suitable for the great majority of land turbines, including the vertical type of Curtiss turbines.

During the last ten years or so, turbine builders have gradually realized the importance of using a light-viscosity oil for high-speed turbines and have designed the lubricating system in such a manner that the pump pressure required to operate the governor gear can be obtained, notwithstanding the use of a low-viscosity oil.

The advantages of such an oil as compared with a heavy-viscosity oil are:

Lower frictional losses (*i.e.*, low bearing temperature).

Rapid removal of heat from the turbine bearings.

Rapid cooling of the oil in the coolers.

Quick separation from water, dirt, and other impurities.

Longer life of the oil.

Greater freedom from trouble.

When circulation oil 1 is not viscous enough to give the pump pressure required for the governor gear, circulation oil 2 or even 3 (in very special cases) must be used.

Marine Turbines.—Marine turbines operate at lower speeds than land turbines and with higher bearing pressures. A heavier viscosity oil is therefore required, and circulation oil 2 will generally be found to be the correct grade.

Geared Turbines (Land and Marine).—The lubricating system for the gears should preferably be separate and distinct from the lubricating system serving the turbine bearings, as the conditions of service are entirely different, and frequently circulation oil 3 will be found best for the turbine gears. Only in rare cases will this oil be the most suitable one for the turbine bearings, as its use frequently will mean:

High frictional losses (*i.e.*, high bearing temperatures).

Slow separation from water, dirt, and other impurities.

Rapid oxidation of the oil and the development of objectionable deposits in the circulation system.

For turbine bearings in geared turbines, when the lubricating system is separate from that serving the gears, a lighter viscosity oil—either circulation oil 1 or circulation oil 2—should preferably be used.

CHAPTER XV

BEARING LUBRICATION OF STATIONARY, OPEN-TYPE STEAM ENGINES

The parts to lubricate are the main bearings, the crankpin, the crosshead and guide, the eccentric straps and sheaves, the valve motion, and the governor.

Main Bearings.—In small engines these bearings are siphon oiled; in larger engines they are ring oiled or are oiled from a circulation-oiling system.

Crankpin.—The crankpin in most engines is oiled by the banjo system, the oil being delivered into the banjo either by a sight-feed drop oiler or by a pipe from the circulation-oiling system.

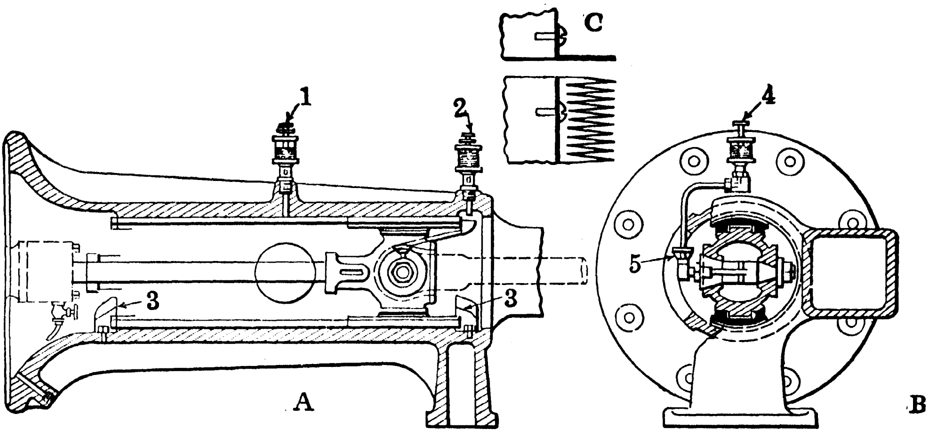


FIG. 76A FIG. 76C FIG. 76B
FIG. 76.—Crosshead and guide lubrication.

Crosshead and Guide.—Lubrication of the crosshead and guide may be accomplished as shown in Fig. 76*A*. Oiler (1) lubricates the top slipper; oiler (2) supplies the crosshead, and the oil leaving these points finally reaches the bottom guide, being retained by the splash guards (3). The crosshead pin may also be lubricated through holes drilled as shown in Fig. 76*B*; the oiler (4) feeds oil to the wiper (5) which is fixed on the crosshead and delivers the oil to the crosshead pin.

The lower crosshead slipper is preferably fitted with a comb, shown in detail in Fig. 76*C*, which touches the guide with a slight pressure and assists in spreading the oil all over the guide; this arrangement is also used to advantage on vertical engines.

Figure 76 shows a bored guide, which is now commonly used for stationary steam engines and which gives greater satisfaction than flat guides give. Great accuracy is more easily obtained when the surfaces can be bored and turned than when they have to be planed.

In the best constructions the lower guide is drilled so that oil from the end wells continuously flows along the horizontal passages and up through these holes, being distributed by means of short transversal oil grooves. In the absence of this arrangement Fig. 77 shows suitable grooving of the bottom guide shoe and chamfered edges at either end instead of combs.

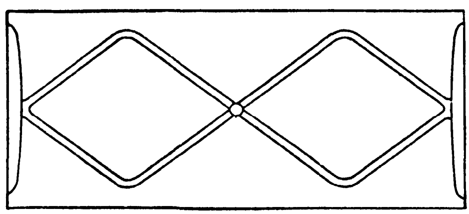


FIG. 77.—Oil grooving of bottom guide shoe.

There is a growing tendency to construct stationary steam engines, whether vertical or horizontal, with a gravity circulation-oiling system, consisting of a pump, top and bottom tank, distributing pipes, return pipes, and a strainer or filter in the circuit, *e.g.*, the filter (Fig. 222, page 594). This system entails many advantages over the ordinary method of distribution, such as greater certainty of the oil's reaching every part and greater ease in controlling the oil supply; greater margin of safety in operation; lower friction brought about by an abundant supply of lower viscosity oil; and an appreciable reduction in oil consumption, when care is taken to avoid leakage throughout the system. The oil wastage in gallons per month will with a good system range between 1 and 2 per cent of the engine horsepower.

The *governor, valve motion,* etc., are usually hand oiled, but in large engines small sight-feed drop oilers are employed for the most important parts.

Bearing Oils.—The bearing oils used for external lubrication of stationary steam engines are usually straight mineral oils, as they come in contact with more or less water of condensation from the glands, which would emulsify compounded oils.

For the crankpins and main bearings, when they do not form part of a circulation system, and when they are heavily loaded or in bad mechanical condition, compounded engine oils, such as one of the marine-engine oils (page 267), are sometimes required to keep them "cool." In extreme cases, castor oil has been used with great success, but its use should be discouraged on account of its tendency to gum. Castor oil is often resorted to in case of trouble and is allowed to remain in use instead of correcting the mechanical defect and introducing a proper grade of engine oil, which will on an average reduce the frictional temperature 50 per cent, as shown in the following example, which is typical.

On the main bearings of a steam engine where castor oil was fed through an oil-circulation system, the rise in temperature of the bearings above room was 17°F. By gradually introducing an oil like marine-engine oil 1 (called "X") the frictional temperature was reduced as follows:

Grade of oil	Temperature, degrees Fahrenheit		
	Bearing	Room	Frictional
Pure castor oil	88	71	17
90% castor + 10% X	86	71	15
80% castor + 20% X	82	69	13
60% castor + 40% X	86	75	11
Pure X oil	90	82	8

This shows a decrease in the frictional temperature of 53 per cent. In changing over from castor oil or any other vegetable or animal oil to an oil largely mineral in character, it is necessary to exercise great care and make the change gradually, as the deposits that have accumulated from such oils are loosened and, if loosened too quickly, cause trouble. The deposits when loosened gradually are caught in the strainers of the oil pump and should be removed as they appear.

It is not unusual to find steam-cylinder oil in use on guides or mixed with the engine oil. This is bad practice, as the great viscosity of the cylinder oil causes great friction and high temperatures; it would be better to introduce a marine-engine oil on guides inclined to be troublesome, assuming that they cannot be made to run cool on the ordinary engine oil.

On very large, long-stroke engines with open guides and tail-rod supports, the engine oil may be so wasteful in splashing away that the use of cylinder oil may be justified. The difficulty with splashing from crankpins in long-stroke engines and providing proper splash guards has in some cases prompted the use of crankpin grease, usually a white grease, in place of oil.

In large crankpin bearings or main bearings on slow-speed engines, whether grease or oil is employed, oil grooves are some-

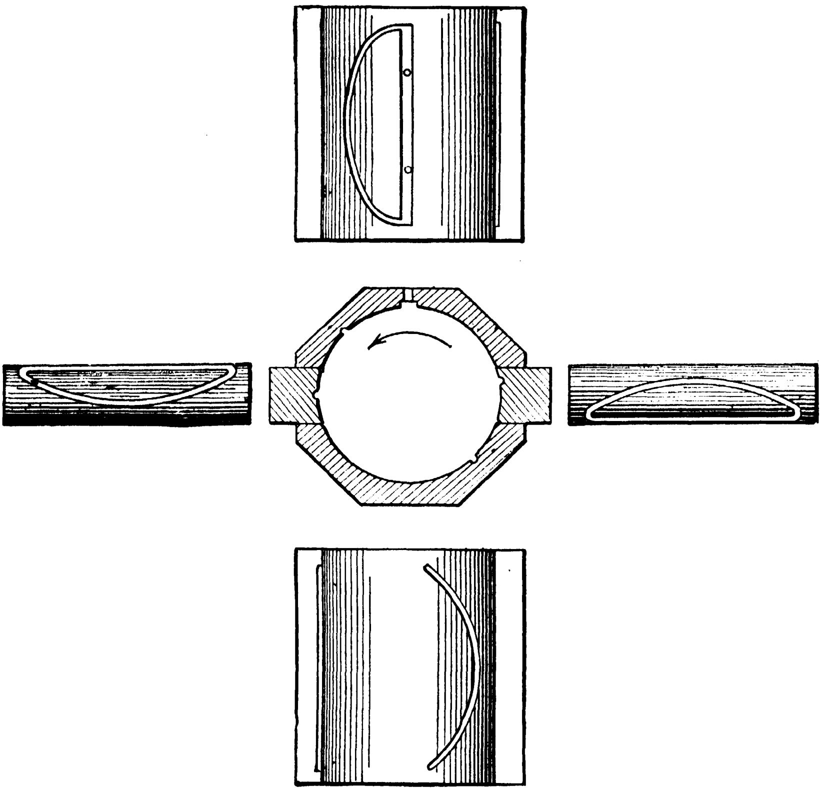


Fig. 78.—Oil grooving a main bearing.

times an advantage when the engine always runs in one direction. Fig. 78 shows the proper way of making the oil grooves in the four parts of a main bearing; the straight oil grooves and chamfered edges collect and feed the oil along their entire length. The bearing pressure is constantly squeezing the oil from the center toward the edges of the brasses, but the curved grooves help to conduct it back toward the center of the bearing.

When grooving bearings, an important rule is to groove only one, not both, of the surfaces, and the grooving should preferably

be done in the female, or enveloping, surface; for example, the bearing surfaces of the connecting-rod brasses are grooved, not the crankpin itself (see Fig. 20, page 121).

As exceptions to this rule note the grooves in Fig. 77 and the distributing oil grooves in long spindle bearings for machine tools (Fig. 114, page 304).

LUBRICATION CHART
For Stationary Open-type Steam Engines

Oil	Viscosity, centipoises at 50°C.	System, horsepower	
		Circulation oiling	Drop feed
Bearing oil 2*	8	Below 250	Below 100
Bearing oil 3	10	250 to 400	100 to 250
Bearing oil 4	13	Above 400	250 to 500
Bearing oil 5, 6	18, 20	For special cases only	Above 500
Marine-engine oil 1 and marine-engine oil 2	56 76	To be used only where bearings are subjected to abnormal pressures or are in bad condition mechanically	

* For bearing oils, see p. 135.

CHAPTER XVI

BEARING LUBRICATION OF HIGH-SPEED ENCLOSED-TYPE STEAM ENGINES

The vertical, high-speed, enclosed type of steam engine has been much developed in England, the engines ranging in size from 10 to 2,500 hp., with corresponding speeds of 800 down to 250 r.p.m.

The horizontal, high-speed, enclosed-type steam engine has come into favor in America for small powers. Both the vertical and the horizontal types may be lubricated by the force-feed circulation system or the splash-oiling system.

Force-feed Circulation.—Figure 79 illustrates a typical force-feed circulation system. The oil pump (1) sucks the oil from the oil reservoir and delivers it at 5 to 15 lb. pressure per square inch through pipes (2) into the main bearings. The crankshaft is hollow, and the oil is forced from the main bearings into the shaft and through oil passages into the eccentric sheaves and crankpins, whence it reaches the crosshead bearings through passages in the connecting rods or tubes attached thereto. The oil leaving the crossheads splashes on the crosshead guides and drops back into the crank chamber. It then flows to the oil reservoir and reenters the oil pump through a strainer, thus completing the circuit. In large engines the guides are fed with a direct supply of oil from the main distributing pipe.

An adjustable oil-relief valve (not shown) is fitted and allows a portion of the oil to overflow back into the oil reservoir. In this way the oil pressure may be adjusted within certain limits. The oil pump should be of ample capacity so that the pump pressure, by means of the adjustable relief valve, can be kept at any desired point. Too small an oil pump or slack bearings decrease the oil pressure or make it necessary to use exceedingly viscous oils, which result in unnecessarily high friction losses.

The oil pump should be placed with its suction strainer elevated to leave room below for water to accumulate. Otherwise, water

is drawn with the oil into the pump and forced through the bearings, tending to emulsify the oil. Water gets into the crank chamber, owing to the presence of ill-fitting glands or "scored" rods. Where the rods enter the crank-chamber top, scrapers

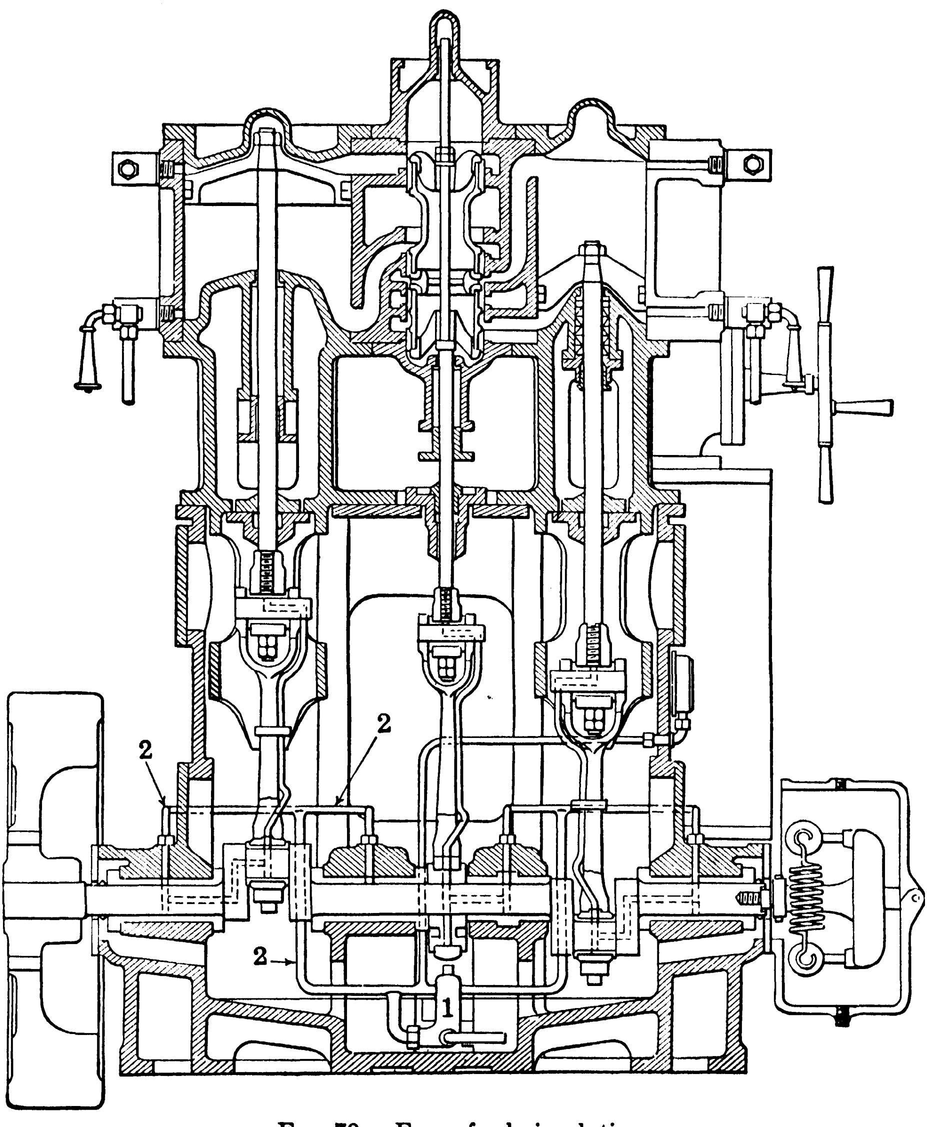


FIG. 79.—Force-feed circulation.

are preferable to glands with soft packing. The oil which is carried up from the crank chamber and scraped off, together with the water, should be drained to an oil separator outside the crank chamber or treated in a steam-heated settling tank to recover as much oil as possible.

Metallic packings are preferable to soft packing in these engines, as there is less danger of scoring the rods than with soft packing, which is easily screwed up too tight. Once a rod is scored, it is impossible to prevent water from traveling through the "ridges" down into the crank chamber.

Slightly superheated steam is an advantage, as less condensation occurs in the cylinders; therefore less water finds its way through the glands.

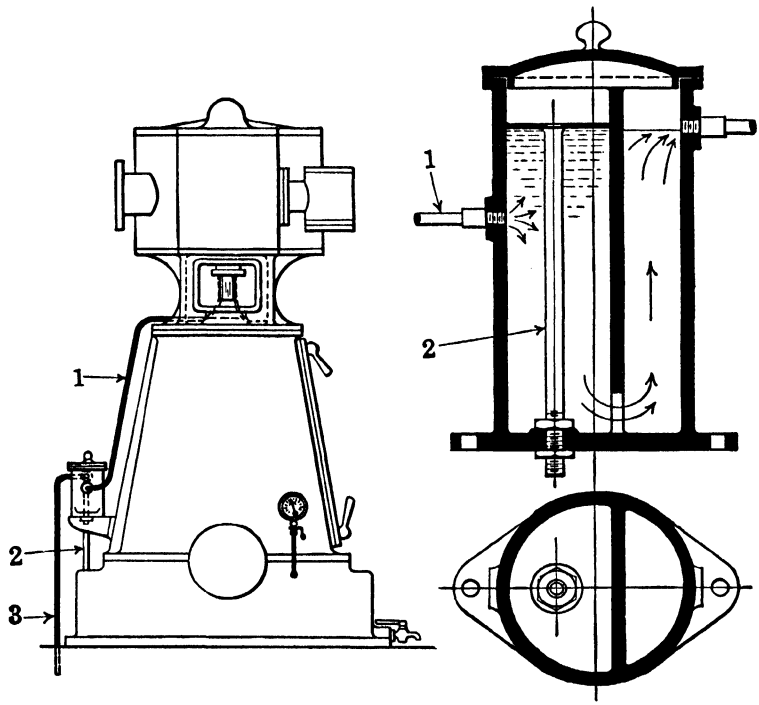


FIG. 80*A*. FIG. 80*B*.
Oil and water separator.

The crank chamber should be systematically drained at suitable intervals.

A drain cock of preferably not less than 1½-in. bore should be fitted at the lowest point in the crank chamber; and if the water can be drained off while the engine is running, this should be done at frequent intervals. Where the draining cannot be accomplished while the engine is running, it should be done before starting up, every time that the engine has had a rest.

When the engine is supplied with wet steam, it is difficult to prevent an excessive amount of water from getting into the crank chamber, unless the rods and oil scrapers are in perfect condition.

When this is not the case the piston and valve rods are constantly splashed with oil which is carried up through the scrapers. Accordingly, a large amount of a mixture of oil and water is constantly scraped off.

Some engines have holes in the crank-chamber top which allow the water and oil to drain straight into the crank chamber; obviously this is bad practice. Other engines have an automatic

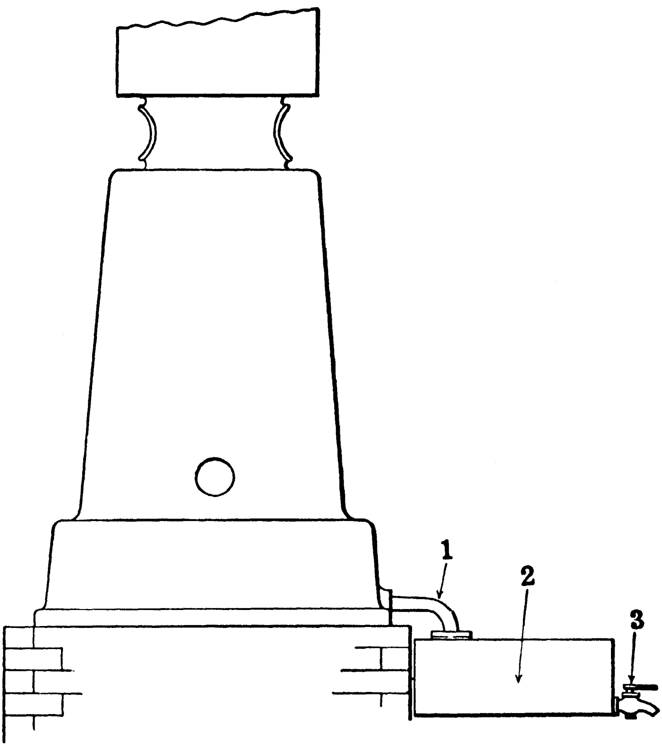


Fig. 81.—Water-drainage tank.

separator, as shown, mounted on the engine, in Fig. 80*A* and in detail in Fig. 80*B*. The drain pipe (1) from the crank-chamber top enters the separator at the side; the oil rises to the surface and overflows through the adjustable pipe (2) back into the crank chamber; the water flows below a baffle and leaves the separator through the drain pipe (3).

As to the water which drains into the crank chamber, Fig. 81 shows a useful arrangement. From the lowest point in the crank chamber, whether this be at the end or in the middle, a pipe (1) is connected to a tank (2) which acts in very much the same way as does the "water leg" for turbines. Once water gets into the

tank, it cannot reenter the crank chamber. Accumulation of water should be drained out periodically.

Every plant should have arrangements for treating daily a portion of the oil in circulation, to free it from water, sludge, and impurities and so maintain its vitality. This system of daily treatment is mentioned (pages 120 and 223) under "Steam Turbines."

In large engines it may be necessary to cool the oil to keep its temperature below 140°F.; a cooling coil made of seamless tube

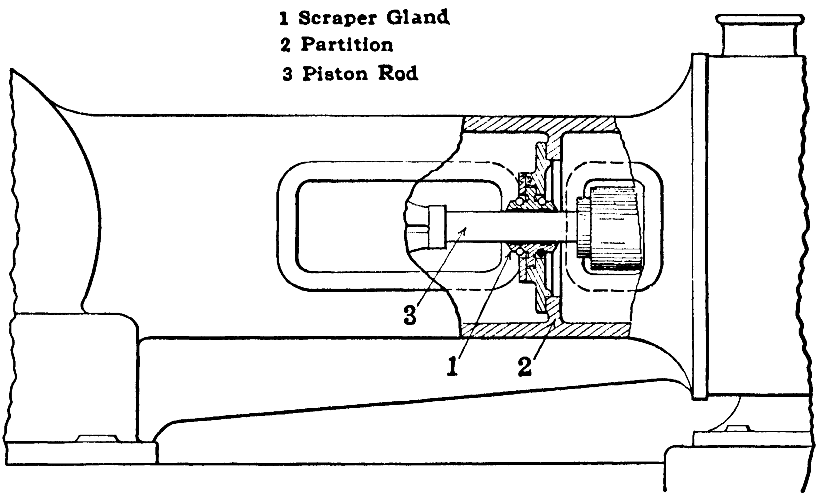


FIG. 82.—Piston-rod scraper gland.

immersed in the oil reservoir is usually all that is required. Practically all that is said regarding oil in connection with steam turbines applies also to forced-lubrication steam engines and will therefore not be repeated here.

The oil-pressure gauge should be watched regularly. If the oil pressure gradually declines, the cause may be bearings requiring adjustment, emulsification of the oil, or choking of the filter.

Some engines have double strainers so arranged that either can be removed for cleaning without disturbing the action of the oil pump. It is of great importance that the strainers be kept clean and free from sludge or dirt.

In horizontal engines it is difficult to prevent oil from splashing on to the piston rod and getting into the piston-rod packing; with saturated steam this is not a serious matter, but with superheated steam the oil carbonizes in the packing. Figure 82 shows a special scraper gland fitted round the piston rod and fixed in a

partition. This arrangement is used in some large uniflow engines and has proved very effective.

Mutton cloths should be used for wiping the crank chamber when cleaning—not cotton waste, which often will cause trouble, as the fluffy fibers stick to the surfaces, are afterward carried with the oil to the pump, and may choke the strainers.

The advantages of forced lubrication over the ordinary methods are many. The lubrication is entirely self-contained. The engines, with correct bearing adjustment and oil pressure, operate noiselessly and will run for years, practically without wear, owing to the perfect film formation. As the engines are double acting, the relaxation of pressure on the upstroke of the pistons gives the oil a chance to force itself thoroughly in between the rubbing surfaces, forming an excellent cushion for the next stroke. In fact, engines may be run with the bearings rather slack and yet without noise; there is not sufficient time during a single stroke to squeeze the oil film out, particularly if the oil has a high viscosity. If an engine uses an oil too low in viscosity, it is inclined to run noisily, and the oil in circulation becomes very warm; the introduction of the correct-viscosity oil will reduce the temperature and give a sweeter running engine.

It is in the author's opinion good practice to run with rather small bearing clearances and low-viscosity oils; such oils give less friction, lower temperatures, separate more easily from water, etc., and last longer than viscous oils.

Forced-feed circulation, when properly arranged, is a very economical oiling system; the consumption of crank-chamber oil ranges from 0.05 to 3.0 g. per brake horsepower hour, the normal average being 1.0 g. per brake horsepower hour. The consumption is highest for smaller engines and when a great deal of water gets into the oil.

Grades of Oil.—The same oils as are used for steam turbines should also be used for forced-lubrication steam engines, and for normal conditions they may be recommended as follows:

LUBRICATION CHART

For Forced-lubrication Steam Engines

Circulation Oil 1.*—For engines below 150 hp.

Circulation Oil 2.—For engines from 150 to 400 hp.

Circulation Oil 3.—For engines above 400 hp.

* For circulation oils, see p. 243.

NOTE.—Certain makes of engines operate with unusually large bearing clearances; others have unusually stout connections between the cylinders and the crank chamber, so that a large amount of heat is carried down from the cylinders into the crank chamber. In either case, circulation oil 2 must be used for engines below 250 hp., and circulation oil 3 for engines above 250 hp.

Splash Oiling.—On account of its simplicity and low cost this system is used to some extent on small horizontal engines of American make, but it is used chiefly for vertical single-acting engines, like the Westinghouse engine (United States) and the Willans central-valve engine (England), the former being made in all sizes up to 200 hp., the latter in sizes up to 1,500 hp. Splash oiling is rarely used for vertical double-acting engines.

The crank chamber is filled with water and oil to a level about 3/4 in. below the underside of the crankshaft. The cranks dip into the bath and splash the oil to the crankshaft bearings, crank-pins, eccentrics, and pistons. When the engine is to be started with a new "bath" after the chamber is thoroughly cleaned, the oil for the bath must be rain water or condensed steam. On no account should hard water be used or water from a source suspected of containing acid, chemicals, or other oils. When the water has been poured in warm (130°F.) the right quantity of oil can be added—usually a layer from 1/8 to 1/4 in. thick, which equals from 3 to 6 per cent of the volume of water in the bath.

The engine is now run slowly at light or no load, until the bath gets well emulsified; not until then should the full load be put on, and only after examining the bath. For this purpose the engine is stopped, and one of the doors removed; the oil will now be seen covering the surface; and after the surface is stirred with a stick, the water underneath must appear milky, yellowish white. If after being stirred the oil flows quickly together in a thick film, there is too much of it in the bath; if it closes over the water only with difficulty, more oil must be added.

During operation of the engine more or less water from the cylinders (condensation), particularly with wet-steam conditions, finds its way into the crank chamber, and the level of the bath rises. An automatic overflow should therefore be fitted; otherwise the oil overflows through the end bearings, and the engine may run short of oil. Figure 83 shows such an overflow arrangement, which will be readily understood. When the level (1)

rises, water from a quiet corner in the bath enters the inlet to the overflow pipe (2), and only the small amount of emulsified oil carried away with the water is lost. Any oil carried in suspension will be retained by the oil separator (3) and can be returned to the bath through the vent pipe fitted higher up on the crank chamber, together with the daily or weekly make-up for loss in oil.

In the Westinghouse engines the make-up oil is fed through oil cups to the main bearings and, leaving these, reaches the bath.

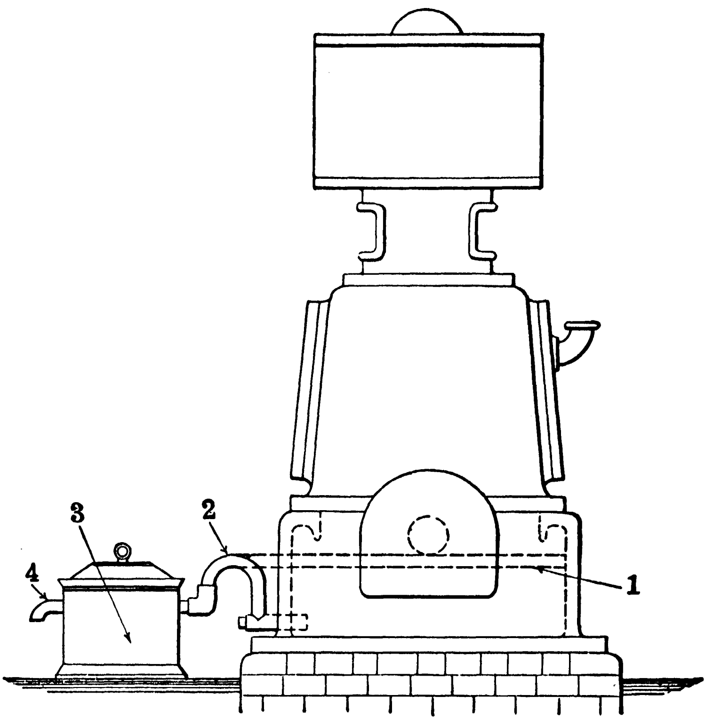


FIG. 83.—Water-overflow arrangement.

When superheated steam is used, and no condensation reaches the bath, some water will evaporate, and it may be necessary to add condensed water to the bath to keep up the level. In such cases the crankcase oil consumption with a good-quality oil becomes exceedingly low. Consumptions as low as 1 pt. per 24 hr. for a 1,000-hp. Willans engine are on record.

The greater the stream of water leaving the overflow (4) the greater the oil consumption; but under reasonably good conditions, a consumption of 0.5 to 3.0 pt. per 24 hr., according to the size of engine, will prove ample.

There are, however, special sources of oil loss, such as loss through end bearings or past the pistons. Figure 84 shows the oil-thrower arrangement of a Willans engine. Any lubricant reaching the oil thrower (1) is returned to the bath through the passage shown. Leakage may occur if the thrower is too far away from the cover (2); drops of oil are ordinarily caught between the edge of the thrower and the beveled edge on the cover; but if the space is too great, oil may get past, without touching the thrower. When the oil has got past this point it may either leak down the outside of the cover or pass along the shaft. To prevent the latter trouble, the clearance between the shaft and the cover must be sufficient so that drops of oil may exist on one surface without touching the other.

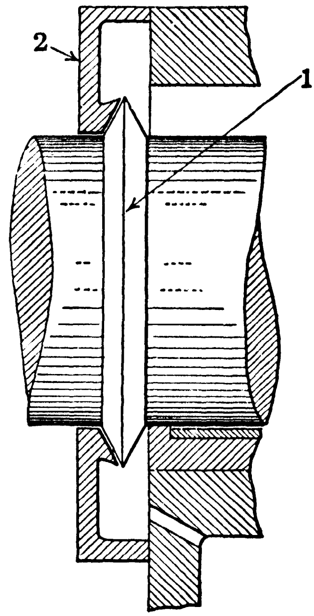


Fig. 84.—Willans oil thrower.

Leakage of oil may also be due to the overflow's being choked with emulsified clots of oil, cotton waste, etc. In that case the bath level rises, the oil finally overflows through the bearings, and, getting caught by the rim of the flywheel, is thrown into the engine room in the vicinity of the flywheel.

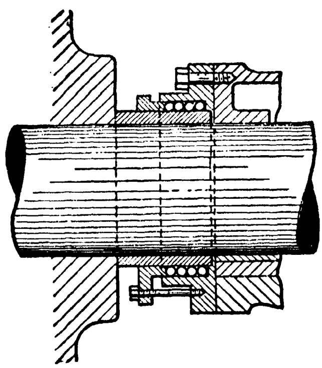


Fig. 85.—Willans stuffing box.

With large shaft diameters the arrangement shown in Fig. 84 is not always satisfactory, and a proper gland may be provided, with very soft packing, which must be tightened up very gently to prevent "grooving" of the shaft. To avoid such wear's taking place on the shaft itself, a bushing is provided as shown in Fig. 85.

When the piston rings in a Westinghouse engine are in bad condition, the oil splash from the crank chamber will be drawn

past the low-pressure pistons in particular and is exhausted with the steam. The quality of the oil has nothing to do with this trouble, and the only remedy is to put the rings in order; rounding the *upper edges* of the rings is always a good precaution, as on the upstroke the rings will ride on the oil film and on the downstroke will scrape off excess oil.

Temperature.—The presence of water in the bath ensures that the bearings shall not reach a temperature higher than 212°F., but for normal running it is preferable to keep it much lower, say 120 to 140°F., after a 2- or 3-hr. run.

With condensing engines this temperature is rarely exceeded, but with noncondensing engines the greater amount of heat from the cylinders often makes the bath uncomfortably hot; a simple arrangement of cooling pipes should then be fitted, and the boiler-feed water may be used as cooling water on its way to the feed pump. Approximately 25 per cent of the feed water will suffice to keep the bath reasonably cool.

There should preferably be no joints in the cooling coils inside the crank chamber to avoid leakage, as, if the water is hard or contains acid, chemicals, or other impurities, a leakage into the bath may destroy the oil. For a similar reason cooling waters should be avoided which are liable to attack the cooling coils, as even pinholes will allow a great deal of water to leak in.

Oils.—If the bath were made with oil, only the bath temperature would quickly rise, owing to the large amount of heat developed by fluid friction in the bearings and by the splashing of the cranks through the viscous oil. When the bath contains only a small percentage of oil, the viscosity of the emulsion is practically the same as for water alone. This was shown by K. Beck of Leipzig.[1] The viscosity, taken by an Ostwald viscometer, of a 10 per cent mixture of castor oil and water was only a little over 1 per cent greater than the viscosity of pure water. It is rather curious that even with fairly high bearing pressures the water emulsion is capable of furnishing adequate lubrication. The explanation is probably that little particles of emulsified oil, or of oil in suspension, attach themselves to the rubbing surfaces and form a coating which prevents metallic contact; and the friction is very low because of the low viscosity of the emulsion, which forms the lubricating film.

[1] *Zeitschrift für Physikalische Chemie*, vol. LVIII.

In the early days castor oil was the favorite lubricant, but it has several drawbacks; it becomes acid and gummy, owing to oxidation, as it is intimately mixed with the hot air in the crank chamber. While, therefore, castor oil produces excellent lubrication and a rich emulsion, it often leads to corrosion of the surfaces, and a sticky deposit accumulates on the connecting rods, etc. The consumption of castor oil is comparatively large, as the water leaving through the overflow is heavily charged with emulsified castor oil. Castor oil is now seldom used; the same oil is used in the bath as in the steam cylinders and valves.

In America straight-mineral dark cylinder oils are generally used; and while they give a moderate degree of satisfaction under the best conditions, the results are not at all good when the engines employ wet steam or when certain hard limy boiler-feed waters are used. The emulsion, which is always poor with a straight mineral oil, breaks down under these latter conditions, resulting in high friction and wear. If the American users of the Westinghouse type of engine knew the results that are obtained by the use of lightly compounded filtered cylinder oils, the dark "Virginia" and similar oils now used straight would soon be displaced by better oils.

Dark cylinder oils, whether straight mineral or compounded, are inclined to become thick and livery, particularly if there is too much oil in the bath. In large engines, where the conditions are usually less trying than in small ones, dark compounded cylinder oils may, however, give good results; but in smaller engines, filtered cylinder oils suitably compounded with fixed oil are much to be preferred. When the steam is wet (boilers priming), and boiler impurities are carried into the engine, some will reach the bath and will tend to thicken the oil. It is under these conditions that dark cylinder oils get "livery," whereas filtered cylinder oils are very little affected, even if there is rather too much oil in the bath. Filtered cylinder oils thus give a much greater margin of safety and prove more economical and more efficient than dark oils. It is a mistake to use a large percentage of fixed oil; 4 to 6 per cent is all that is required. With more fixed oil the emulsion becomes unnecessarily rich, and more oil is lost through the overflow.

Small engines are sometimes lubricated with a bath of circulation oil, but 15 to 20 per cent of oil is then required as compared

with 3 to 6 per cent when cylinder oil is employed. Certain small engines have the bearings more or less enclosed, and the oil holes are rather small. If cylinder oil were used in the bath, small clots of emulsified oil would choke these small openings, and circulation oils must therefore be used for such engines.

Sticky deposits may develop on the rods, etc., as already mentioned in reference to castor oil; similar black deposits may be produced with cylinder oils, particularly so with dark oils, and they will appear on the rods in peculiar patterns or streaks caused by the motion of the rods and consist of water, oil, oxidized oil (insoluble in petroleum spirit), and a small percentage of iron and iron oxide (wear). The cause of the deposits may be inferior mineral base in the oil (presence of too much coloring and bituminous matter) or inferior fixed oil (too much free fatty acid); or, again, the quality of the oil may not be at fault, but the temperature of the bath may be above 140°F., which is a critical temperature as far as oxidation of the oil is concerned. Shortage of oil in the bath will also bring about deposits, but they will then be found rather rich in metallic contents, indicating excessive wear.

LUBRICATION CHART

For High-speed, Enclosed-type Engines, Employing the Splash-oiling System

Description	Grade of oil	Percentage of oil used in bath
Small, horizontal engines, operating in ordinary engine rooms.....	Circulation oil 1 or 2*	100
As employed in steam motor wagons	Circulation oil 3 or similar oil of even higher viscosity	100
Vertical engines:		
Up to 50 hp..................	Circulation oil 2 or	15
	cylinder oil 2 F.L.C.†	4 to 6
Up to 300 hp..................	Cylinder oil 2 F.L.C.	4 to 6
Above 300 hp..................	Cylinder oil 3 F.M.C. or	3 to 4
	cylinder oil 3 D.M.C.	3 to 4

* For circulation oils, see p. 243.

† For cylinder oils, see table page 408.

CHAPTER XVII

CRANK-CHAMBER EXPLOSIONS

In many modern high-speed engines, whether they be steam, gas, petrol, or Diesel engines, the crank chamber is filled with oil spray—a more or less dense mist of fine oil particles. These engines are acknowledged to be safe and reliable in operation, as far as lubrication is concerned, notwithstanding what is probably a fact, that most of them when running would explode were a spark to be formed inside the crank chamber.

It is a well-known fact that to make an explosive mixture with air, an inflammable *gas* of some kind is not essential. Any sufficiently inflammable substance in the form of *fine dust* will produce this effect if present in the requisite proportion, *e.g.*, in the case of many explosions in coal mines. A mixture of air and coal dust can be made to explode when the coal dust reaches a certain percentage; and as soon as a spark or a naked flame is formed or brought within the danger zone an explosion will occur. An explosion of this character occurred in an oil-cake mill, the air being heavily laden with fine seed dust; the mixture was fired by a spark from a dynamo, and many lives were lost. Another explosion occurred in a flour mill, sparks from a hot bearing firing the mixture of air and flour dust.

Coming back to the enclosed high-speed engines, it is obvious that, from the time of starting, an increasing amount of oil spray is formed owing to the smashing action of the moving parts on the stream of oil escaping from gudgeon pins or crossheads and crankpins. When the engine has been running for some time, the air will contain a certain constant amount of "oil mist" in accordance with the conditions of speed, ventilation, etc., of that particular engine. In very large engines, *e.g.*, large enclosed-type marine Diesel engines, it is doubtful whether they ever contain sufficient oil mist to be capable of exploding; but in smaller and much higher speed engines, the danger of explosion is ever present.

In 1911 an enclosed steam engine, 300 hp. with forced-feed circulation, exploded in a large hosiery factory. On a Monday

morning the engineer had gone to the engine room, started the engine, and left the powerhouse; a few minutes later the engine exploded. This is what happened:

During the week end the engineer had tightened up the brasses on the low-pressure crosshead, and on Monday morning the engine was started up without examination as to whether this bearing had been tightened up too much, which unfortunately was the case. After a few minutes the crosshead got hot; the heat spread to the cast-iron slippers, which work vertically in circular guides about 8 in. in diameter. The clearance was only about 0.01 in. when cold and 0.002 or 0.003 in. with the engine warm; consequently, the excessive heat conducted from the crosshead pin caused the slippers to expand and seize. The circular guides broke, and flying sparks from the slippers fired the mixture of air and atomized oil in the crank chamber. The governor casing blew off; the opposite wall of the engine room fell out, while one of the other walls was moved 4½ in.; and the roof of the engine room was blown away.

Another disaster took place on a British battleship. An enclosed steam engine exploded and killed a number of men. The papers reported that the explosion was due to carelessness on the part of one of the men, who approached the engine with a naked light just after it had been opened and the inspection doors removed, so that the crank chamber was still full of the mixture of atomized oil and air.

Similar explosions have been reported in connection with Diesel engines installed in submarines belonging to one of the large Continental powers, and in several cases the explosion was due to sparks in the crank chamber owing to seizing of one of the pistons. This would seem to indicate that as far as cylinder lubrication is concerned, the greatest care should be taken in designing the lubricating system and in using such oils as will ensure as safe and clean lubrication as possible of the pistons, particularly so in the case of Diesel engines for naval purposes, where high speed and short connecting rods are the characteristic features, owing to the cramped space available for the engines.

Several explosions have happened in the past with enclosed high-speed gas engines, due to exactly similar conditions, *viz.*, a mixture of air and atomized oil. It is a fact worthy of note that at least one firm of engine builders in England now ventilate

their enclosed gas engines and Diesel engines by fitting a small fan that removes from the crank chamber any gases that may pass the pistons, as well as the finest oil vapor, thus making the possibility of an explosion very remote indeed.

This system appears to be particularly desirable for high-speed naval Diesel engines and has been used in Continental submarines; to avoid excessive loss of oil, the fan discharges through a separating tank, in which baffle plates cause a portion of the oil to "condense" and settle out.

CHAPTER XVIII

BEARING LUBRICATION OF MARINE STEAM ENGINES

Hand oiling is still used, the practice being to pour oil from an oil feeder into oil cups, say during four to eight revolutions of the engine every half hour. The bearings get flooded with oil after each oiling, and thereafter the oil film is gradually squeezed out, and lubrication becomes less and less efficient until such time as the bearings are oiled again. Obviously, this method is both wasteful and inefficient.

The better method now most frequently employed is to have oil cups fitted with siphon wicks which siphon the oil from the cups and deliver it into oil pipes leading to the various bearings. Siphon oil boxes are fitted near the tops of each cylinder and distribute the oil through feed pipes ending in "wipers," which are touched by oil-receiving boxes fixed on the moving parts, at the moment that these boxes reach their highest positions; the oil is finally guided to the various points through pipes fixed to the moving parts.

A siphon box is fitted over each main bearing with two or more oil feeds according to the size of the shaft; from these boxes may also be taken oil feeds for the crankpins, when the latter are arranged for "banjo" oiling. An oil box is fitted for each crosshead guide, and a comb fitted to the bottom end of the slipper dips into the oil well and carries the oil up on the guide which is usually water cooled.

The oil feeds vary with changes in temperature, the oil feeding more quickly when warm, owing its lower viscosity. The oil feed is much dependent on the oil level in the cups. The siphons feed more slowly when the oil level is low; it is therefore necessary to keep it as uniform as possible by frequently replenishing the oil cups.

A better system is to replenish the various siphon oil cups not by hand but from a centrally placed oil tank, feeding adjustable quantities of oil through the feed pipes, each of these having a

sight-feed arrangement by which the oil feed can be ascertained going to the corresponding oil cup. If, for example, one feed pipe is feeding 60 drops per minute to one of the oil cups, the latter distributing by siphons the oil to several points, then the oil level in this cup will quickly adjust itself automatically to such a level that the oil siphons, all told, will siphon out 60 drops per minute. If they feed more, the oil level will gradually decrease until a point is reached when the oil feeds, all told, amount to 60 drops per minute. The control of the oil feeds from the central oil tank can best be done by mechanically operated lubricators, which start and stop feeding with the engine.

Experience has proved that the installation of such a central distributing-oil tank, preferably in connection with mechanically operated lubricator pumps, will save from 40 to 60 per cent of the total amount of oil consumed for external lubrication.

There is always a greater or lesser amount of condensed steam finding its way down the piston and valve rods and dropping all over the external moving parts, and in case of a hot bearing the cold-water hose is frequently applied. Sometimes a small trickle of water is allowed to run into or on to those bearings which are inclined to run rather warm. When oils pure mineral in character are used, the water will displace the mineral oil, and the bearings will heat and may seize.

Marine-engine oils should therefore be compounded with a suitable percentage of good-quality fixed oil, so that they will emulsify freely with water and form a rich and creamy lather. Good-quality marine oils, while they combine satisfactorily with water, will give more efficient and more economical lubrication if they are used without water. The oil when leaving the bearings, usually in a more or less emulsified condition, is run to waste into the bilges, as it is impossible to recover it from the emulsified waste oil.

Marine-engine oils should contain only a small percentage of fatty acid, say less than 2.8 per cent F.F.A., so as not to cause corrosion or pitting. The fixed oil should not produce a disagreeable odor exposed to the heat in the engine room, nor should that used for compounding be of a drying nature, but semidrying oils like rape oil will give good service. Castor oil was at one time much used and still is, largely in the East, but is expensive when used alone. It can, however, be mixed with

mineral oil in the presence of an animal oil, say 20 per cent castor, 6 per cent lard oil, and 74 per cent heavy-viscosity mineral oil—preferably Texas, Russian, or other asphaltic base to get a low setting point. The lower the setting point and the greater the percentage of good-quality fixed oil of reasonably low cold test the less will the oil be affected by climatic changes.

The bearings of large marine steam engines require oils of great oiliness to give the necessary margin of safety under the severe operating conditions. Pure mineral oils of the requisite oiliness do exist, but they are so viscous that they will not siphon properly, and they feed irregularly owing to poor cold tests. The admixture of fixed oils having great oiliness is therefore dictated not only by the presence of water but also by the necessity of keeping the cold test and viscosity of the finished oil reasonably low. Blown rape oil, blown cod oil, or blown whale oil, preferably the first, are used to the extent of 10 to 25 per cent, the fixed oils being usually blown until they have a viscosity of 720 to 1400 sec. Saybolt at 210°F. Such very viscous fixed oils raise the oiliness and the viscosity of the mineral base appreciably without unduly raising the setting point.

The table below gives typical readings of three marine-engine oils which will serve for all marine purposes where compounded oils are needed. The important figures are those for viscosities, cold tests, and compound; the figures for specific gravity and flash point are of little consequence.

Large engines and vessels navigating in hot climates need higher viscosity oils than smaller engines or vessels operating in colder climates, but only practical tests extending over a period of, say, 3 months can decide which of the three grades should be preferred and what percentage of compound it should contain.

MARINE-ENGINE-OIL TABLE

Marine-engine oil	Specific gravity	Viscosity number*	Viscosity, centipoises at 50°C.	Open flash point	Cold test	Compound, per cent
1	0.920	9	56	400	25	10 to 20
2	0.930	10	76	405	25/30	10 to 20
3	0.940	12	125	410	30/35	15 to 25

* See table, p. 57.

The high-viscosity oils are usually the more economical, but they may be unnecessarily viscous and thus waste power in creating too much "oil drag" in the bearings.

Forced circulation has during recent years made great progress in naval ships both in Europe and in the United States, not only for steam turbines and auxiliary high-speed enclosed-type steam engines but also for the large reciprocating-type main engines in destroyers and other craft.

The working parts including the crossheads are enclosed in an oiltight casing, packed glands being provided for the piston and valve rods to prevent too much water from getting into the oil in circulation. Observation windows and electric lights may be fitted to watch the moving parts. The oil is supplied by reciprocating pumps operated by the engine itself or independent thereof. It may be forced into the hollow crankshaft, holes being drilled radially at each main bearing, crankpin, and eccentric, the oil from the crankpin continuing its way through a tube fitted to the connecting rod into the crosshead bearing, finally reaching the crosshead guides.

The oil-delivery pipes may also deliver the oil into the main bearings first of all, the oil thence reaching the hollow crankshaft, etc., as is customary on land engines.

The oil-supply system is frequently made in duplicate.

The oil collecting in the oil wells is pumped away by independently operated pumps, fitted with suction strainers, being delivered through a filter to a "settling tank," finally reaching the storage tanks ready to be circulated afresh.

Main engines fitted with forced oil circulation have been inspected after the vessel has done 20,000 miles; the toolmarks in the white-metal bearings were found to be still visible, and no measurable wear had taken place.

The risks of accidents due to hot bearings caused by insufficient oil supply are practically eliminated by this system; there is a great saving in the time and expense that were required with siphon lubrication in rebabbitting, adjusting, and examining bearings after each voyage. The cost of lubrication is also much reduced by forced oil circulation, and the engines operate much more quietly.

Auxiliary engines which are now frequently fitted with a full force-feed circulation system should preferably have the

cylinders raised so high above the crank-chamber top that no part of the piston and valve rods entering the cylinder or valve glands will enter the scraper glands fitted in the crank-chamber top. If this is arranged, no oil from the crank chamber can possibly enter the steam cylinders, which is important with a view to preventing oil from reaching the boilers.

The *oils used for force-feed circulation systems* must be similar to those used for steam turbines; *i.e.*, they are circulation oils (see page 243). *Circulation oil* 2 is used on most small auxiliary high-speed engines; *circulation oil* 3, on large slower speed engines and larger auxiliary high-speed engines.

One might ask why those oils—pure mineral in character and lower in viscosity than the compounded marine-engines oils—can

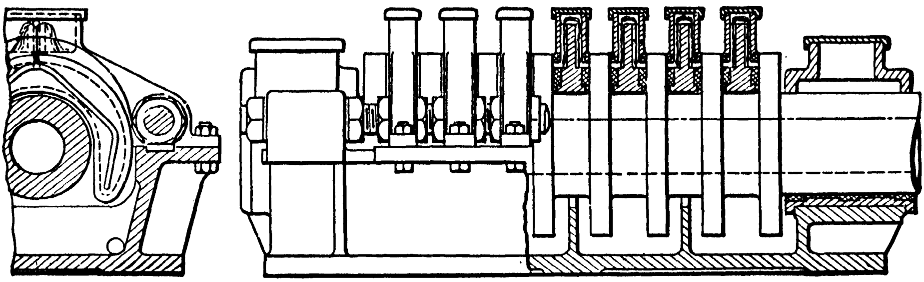


FIG. 86.—Horseshoe thrust bearing.

replace the latter and with such great success. The answer is simply that the oil is supplied to all bearings *in abundance*, not only supplying a complete lubricating film but also continuously *removing frictional heat* from the bearings, which therefore run *much cooler*. The bearings do not become contaminated with water, and as the revolving parts practically "float" on a complete oil film, wear is almost eliminated, and the results are excellent from every point of view.

It is to be hoped that the merchant marine will take advantage of the experience gained by the various navies with force-feed circulation, which undoubtedly is very superior to the systems now generally employed.

Thrust Bearings.—Figure 86 illustrates the horseshoe type of thrust bearing still almost universally used for marine steam engines. The collars on the shaft press against the horseshoes, which are adjustable in a fore-and-aft direction so as to distribute the load more or less evenly between them. Changes in temperature difference between shaft and horseshoes alter the distri-

bution of load and cause heating of certain collars and shoes, so that a hot thrust is by no means uncommon; in fact, the thrust bearing often gives the engineers more trouble than any other bearings or part of the engine-room machinery. The oil is fed by siphons from the top and led into oil grooves of various "fancy" patterns. The collars are often arranged to dip into the oil and carry it up with them. The oil bath is sometimes fitted with a cooling coil, but it is more effective to cool the horseshoes themselves, which is often done in large and important thrust bearings (see Fig. 87).

The lubrication is, however, always poor, as the centrifugal force throws the oil away from the points where it is most needed;

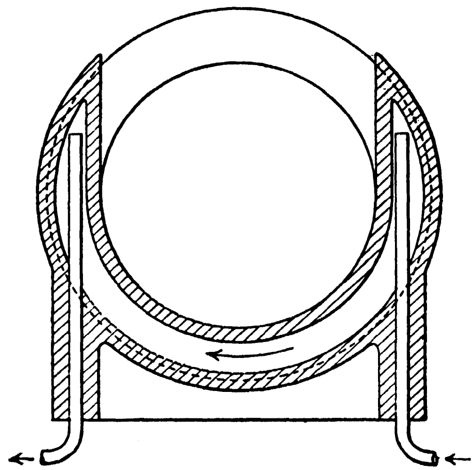


FIG. 87.—Cooling the thrust.

the bearing pressures allowed are therefore low—usually 50 to 70 lb. per square inch—with a mean surface speed of 500 ft. per minute, but with the best cooling arrangements and perfect workmanship a bearing pressure of 100 lb. per square inch and a mean surface speed of 600 ft. per minute has been accomplished, and in other cases a pressure of 60 lb. per square inch with a surface speed of 800 ft. per minute. The friction is high, often consuming 5 per cent of the shaft horsepower; the rubbing surfaces are in only a boundary-lubricated condition, the coefficient of friction being approximately 0.03.

The Michell single-collar thrust bearing (see page 175) will no doubt come more and more into general use, not only for marine turbines but also for marine steam engines, as with a

little intelligent attention it gives no trouble whatsoever and consumes less than one-tenth of the friction ordinarily wasted in the horseshoe type of thrust bearing.

Stern-tube Lubrication.—A large majority of ships are fitted with lignum-vitæ stern-tube bearings, the propeller shaft being fitted with a bronze liner, and the lignum vitæ being placed as strips 2 to 3 in. wide with 2-in. spaces between the strips. Salt water is usually the only lubricant used in these bearings, but occasionally the stern-tube gland is fed by a Stauffer grease cup through which a suitable grease can be fed into the gland with a view to reducing the considerable amount of friction generated here.

Unquestionably, there is a very great frictional loss in the lignum-vitæ stern-tube bearings, and the only way to reduce this frictional loss is to fit the bearing with an outer gland, as in the case of the Cederwall, Vickers, or similar type of packing. Thus enclosed, the lignum vitæ can, if desired, be replaced by proper bearing metal, and in any case the stern-tube bearing can be efficiently lubricated by means of oil or thin grease. This means a great saving in power and also entails the advantage that where the vessel gets into shallow waters, as is the case with a number of river boats or coasting steamers, the entrance of mud, sand, or other impurities is entirely obviated, thus preventing trouble and giving much longer life to the stern-tube bearing, the wear being practically eliminated.

Another advantage is that galvanic corrosion, rusting, and pitting of the shaft cannot take place, assuming, of course, that the lubricant employed is of reasonably good quality.

An arrangement patented by Vickers and Sons, Leeds, is illustrated in Fig. 88 and was referred to in *Engineering*. They write as follows:

> This appliance was fitted to two twin-screw hopper barges constructed for the Clyde Navigation Trustees by Messrs. Fleming and Ferguson, Limited, of Paisley. After running two years the shafts were examined and were found to be in very good condition. They were again examined after 3 years' continuous work, and the wear was found to be less than $\frac{1}{32}$ in. of the total diameter of the shaft in the bush, so that it was not considered necessary to true up the bushes. When one remembers the peculiar gritty nature of the Clyde water and that the barges are often in close proximity to

little intelligent attention it gives no trouble whatsoever and consumes less than one-tenth of the friction ordinarily wasted in the horseshoe type of thrust bearing.

Stern-tube Lubrication.—A large majority of ships are fitted with lignum-vitæ stern-tube bearings, the propeller shaft being fitted with a bronze liner, and the lignum vitæ being placed as strips 2 to 3 in. wide with 2-in. spaces between the strips. Salt water is usually the only lubricant used in these bearings, but occasionally the stern-tube gland is fed by a Stauffer grease cup through which a suitable grease can be fed into the gland with a view to reducing the considerable amount of friction generated here.

Unquestionably, there is a very great frictional loss in the lignum-vitæ stern-tube bearings, and the only way to reduce this frictional loss is to fit the bearing with an outer gland, as in the case of the Cederwall, Vickers, or similar type of packing. Thus enclosed, the lignum vitæ can, if desired, be replaced by proper bearing metal, and in any case the stern-tube bearing can be efficiently lubricated by means of oil or thin grease. This means a great saving in power and also entails the advantage that where the vessel gets into shallow waters, as is the case with a number of river boats or coasting steamers, the entrance of mud, sand, or other impurities is entirely obviated, thus preventing trouble and giving much longer life to the stern-tube bearing, the wear being practically eliminated.

Another advantage is that galvanic corrosion, rusting, and pitting of the shaft cannot take place, assuming, of course, that the lubricant employed is of reasonably good quality.

An arrangement patented by Vickers and Sons, Leeds, is illustrated in Fig. 88 and was referred to in *Engineering*. They write as follows:

> This appliance was fitted to two twin-screw hopper barges constructed for the Clyde Navigation Trustees by Messrs. Fleming and Ferguson, Limited, of Paisley. After running two years the shafts were examined and were found to be in very good condition. They were again examined after 3 years' continuous work, and the wear was found to be less than 1/32 in. of the total diameter of the shaft in the bush, so that it was not considered necessary to true up the bushes. When one remembers the peculiar gritty nature of the Clyde water and that the barges are often in close proximity to

dredges which are disturbing the bed of the river, this result will be accepted as very satisfactory. The section is almost self-explanatory. It will be seen that on each side of the floating packing there are two packings; and next to the guard ring there are elastic disks which grasp the shaft like the sleeve of a diver's jacket. The inner one is a fine elastic woollen felt, and the outer of a special composition of a slightly elastic nature which is unaffected by either sea water or oil. Inci-

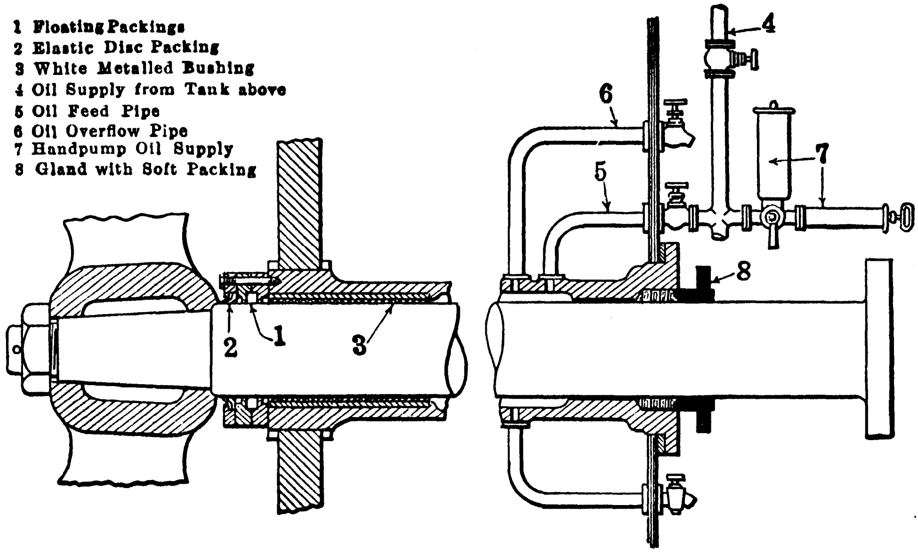


FIG. 88.—Vickers' stern-tube packing.

dentally, the application of oil here reduces the friction, and as the friction resistance within the stern tube is a large proportion of the total friction of the engine and shaft, the advantage is very considerable.

The continuous bronze liners now often fitted, which are carried right into the propeller boss, protect the shaft from galvanic corrosion but do not prevent the entry of sand, so that whatever system of lining or bushing (cast iron, white metal, or lignum vitæ) is employed, many advantages are always obtained by enclosing the stern tube and having a proper oiling arrangement fitted.

CHAPTER XIX

RAILWAY ROLLING STOCK

BEARING LUBRICATION OF LOCOMOTIVES, TENDERS, AND CARS

Axle boxes.—Axle boxes are termed inside or outside according to whether they are inside or outside the wheels. Generally speaking, tenders and cars have outside axle boxes, and locomotives inside boxes; some locomotives, however, have the wheels inside the frames and the axle boxes outside.

Figure 89 shows an *outside axle box.* A door is formed in the front portion of the box. To prevent rain water from entering the box through the joint, the box may project above the door, as

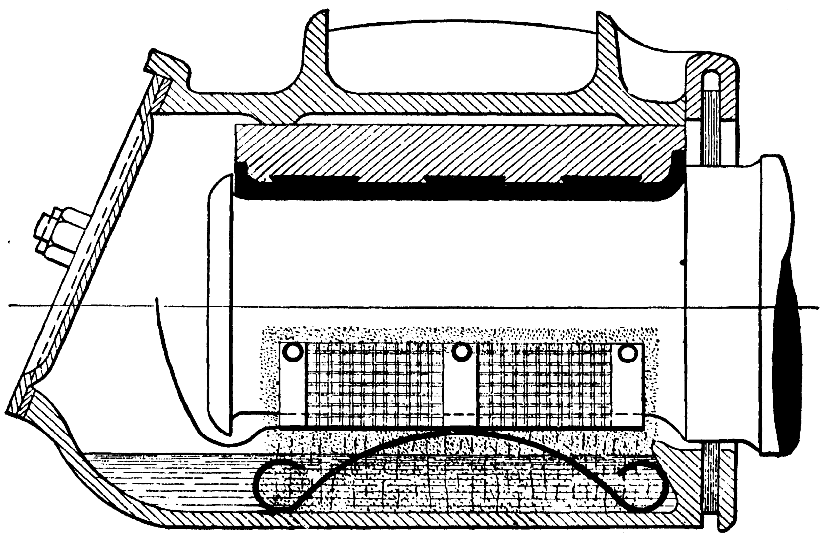


FIG. 89.—Outside axle box.

shown; another solution is to have attached to the door a sheet-metal rain guard which projects over the top of the box (Fig. 90). For the same reason the door should be so designed as to prevent water from getting in at the sides and bottom. At the wheel side of the box is a dust guard, usually made of wood, in two halves, which are forced gently against the shaft by springs. One type

of dust guard made of lignum vitæ has oil pads fitted in little recesses in both halves; the bottom pad has two siphons, the ends of which are immersed in the oil reservoir and thus lubricate the dust guard and prevent wear.

Most dust guards get little or no lubrication, and when they are worn they no longer keep the dust out so efficiently as one might desire.

Between the top of the "brass" and the cover of the axle box, to which the weight is transmitted through the springs, is placed a hardened cast-steel liner or wedge piece, which serves to distribute the load uniformly over the whole of the brass.

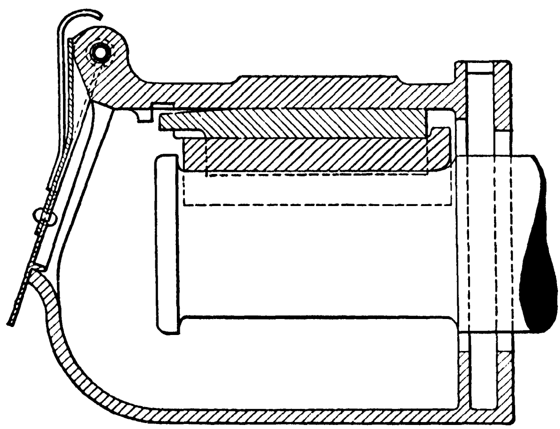


FIG. 90.—Axle box with rain guard.

Inside axle boxes consist of two almost semicircular castings with vertical side plates which fit the horn plates; the lower half is suspended from the upper half by bolts, and the springs rest upon the upper half.

Journals and Bearings.—It has become a general practice to roll the journals of crankpins and axle journals with a hard-steel roller, in order to compress the surface and make it very tough and capable of resisting wear. The roller is held in the tool post of the lathe after the finishing cut has been taken and is forced against the journal. This same method is also frequently used for rolling the white metal in babbitted bearings.

As regards bearing metals, locomotive driving and trailing bearings are usually bronze lined with white metal, and the tendency is to extend the use of white metal as a lining for bearings. The reason for this is that a good white metal combines the

necessary strength with plasticity. It contains hard grains which transmit the pressure to a plastic matrix. The hard grains prevent excessive wear, and as they are embedded in a yielding matrix the load is evenly distributed over the entire surface.

With phosphor bronze, unless the bearings are very carefully scraped together, the load is not so evenly distributed; and in the case of shocks and vibration, local heating may easily occur, causing a hot bearing.

It is a well-known fact that in running down a long gradient, crankpins with bronze bearings are liable to heat, owing to excessive shocks in the bearings caused by the absence of steam in the cylinders, which otherwise would "cushion" the blow at either end. Strips of white metal embedded in the crankpin bearings help to prevent such heating.

Another reason for the wider adoption of white metal is that should the bearing seize, the shaft is only little affected, and the bearing can be rebabbitted at a small cost.

A large proportion of lead in white metal is not desirable, as it causes increased friction and, being a bad conductor of heat, does not allow the heat to be dissipated so readily; consequently, the bearings run warmer. Furthermore, lead is more easily attacked by acids which may be present in the oil.

It is necessary for the white metal to be supported by brass or cast iron of sufficient thickness to avoid distortion under running conditions. If the brasses are too light, they may crack or at least run exceedingly warm. This action causes the edges of the brass to pinch the journal and makes it very difficult for the oil to do its work properly.

As mentioned above, phosphor bronze can be used as a bearing metal only when the faces are very accurately scraped together. In the case of white metals, however, such careful fitting is not necessary, as the bearing surfaces will bed themselves together more readily.

Of recent years, bronzes of a new type called "plastic bronzes" have been used, particularly in the United States. The difference between them and the white metals is that they are made up of plastic substances embedded in a hard matrix, whereas the white metals are made up of hard substances embedded in a soft matrix. There seems to be a divergence of opinion as to the utility of these plastic bronzes.

THE PROPORTIONS OF ROLLING-STOCK JOURNALS

It is very important that the load on journals shall not be transmitted eccentrically. Take a journal with a diameter D and length L, the load being not in the center but transmitted at a point x in. away from the center (Fig. 91); then the bearing pressure at the extreme ends of the bearing will be

$$\frac{P}{D \times L}\left(1 \pm \frac{6x}{L}\right)$$

To take an example: Let P = 16,000 lb., D = 8 in., and L = 10 in. If the load is central, the pressure per square inch will be 200 lb. uniformly distributed. If 2 in. are added to the inside of the box, making the length 12 in. and x equal to 1 in., then the maximum and minimum pressure per square inch will be 249 and 83 lb., respectively, at the outside and inside edges, while the average pressure is only 166 lb. per square inch. This will indicate that it is often preferable to accept an increased pressure per square inch rather than create an eccentric loading.

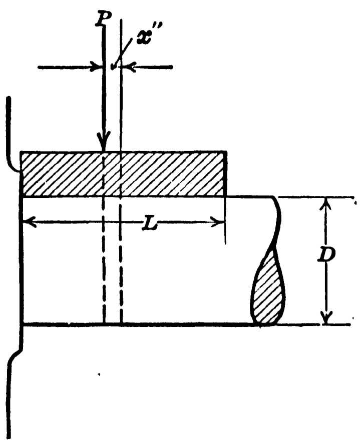


FIG. 91.—Eccentric loading.

On locomotive driving journals the brass covers half the journal, and the pressures per square inch are usually somewhere about 200 lb.

In the case of car and tender bearings, the arc over which the brass touches the journal is usually 90, occasionally 120 deg., and the pressure per square inch of projected area is usually from 300 to 325 lb.

The small space available, particularly on narrow-gauge railways, often makes it difficult to give locomotive bearings the dimensions required for cool running. The journals can always be made strong enough, but the difficulty is to make them long enough. When a bearing runs consistently hot, an increase in journal diameter is no remedy, as, although the bearing pressure per square inch is reduced, the surface area and surface speed of the journal are both increased, so that, notwithstanding the

larger radiating surface, no advantage is obtained. With greater length of the journal, the surface area is increased, but not the surface speed, and the result is a cooler running bearing.

Some interesting information was given by Robson in an article[1] in which he gives an empirical formula for judging whether a bearing will be inclined to overheat or not.

Let S = the maximum continuous speed of the vehicle in miles per hour.
D = the diameter of the wheel in inches.
W = the weight on journal in tons.
L = the effective length of the journal in inches.

Then

$$K = \frac{W \times S}{L \times D}$$

K being a constant, which is determined by actual experience.

The article gives values for this constant for different bearings, all of which are white metaled and, except in the case of crankpins, lubricated by means of a pad or oil-saturated waste below the journal.

Robson gives his experience with various bearings inclined to heat and with others that, owing to longer journals, ran reasonably cool.

A summary of his recommendations is given in the following table:

Type of bearings	Maximum speed, miles per hour	Value for K
Inside locomotive journals on carrying axles and bogies	70	0.8
Outside journals on locomotives and tenders	70	0.9
Crankpin journals	70	4.0 to 4.5
(For some inside crankpins K was 5.6 which was too high but could not be reduced on account of the narrow track)		
Carriage journals	70	0.7
Goods and mineral-wagon journals	25	0.5

[1] *Engineering*, Nov. 25, 1910.

METHODS OF LUBRICATION

Locomotive Axle Boxes.—The usual practice is by means of siphon oil feeds (tail trimmings) from auxiliary oil boxes, the oil being led through tubes to the top of the bearings, entering the bearing through either a central oil hole into one longitudinal oil channel at the top of the brass or two oil holes leading into two oil grooves forming a slight angle with the journal. By this system the oil enters the bearing only with difficulty, except at the two bearing ends, and, once it has left the bearing, is lost.

In modern systems the boxes are fitted with oiling pads underneath the journals, or they are filled with waste, preferably woolen waste thoroughly saturated with oil. The oil that enters the bearing is caught by the pad or the waste and distributed over the entire underside of the journal. The lower edges of the brass are eased away, so as to facilitate the entrance of the oil film between the journal and the brass.

The most recent practice is to install mechanically operated forced-feed lubricators on the frame or in the cab, from which the oil is automatically distributed to the axle boxes under pressure. Test cocks are provided in suitable positions, so as to regulate and test the oil feed. This method is an ideal one, as it ensures a feed of oil to the bearings in direct proportion to the revolutions of the journal; also, it is unquestionably the most economical, and the oil reaches the bearings with absolute certainty, the distribution being entirely automatic.

Where mechanical lubricators are used for feeding oil both to the cylinders and to the axle boxes, such lubricators should have two compartments, so that a bearing oil may be used for the axles, and cylinder oil for the cylinders. Obviously, it is ordinarily not desirable to use cylinder oil for the axle boxes, as it is far too viscous and causes unnecessarily high temperatures of the journals and boxes.

In the case of bogie boxes, oiled through siphons from the top, they are exposed to rain or to the spray of water from the cylinder waste-water cocks. If sufficient water enters the oil well on top of the box, it will dislodge the oil and thus cause a heated journal. There is a general tendency among engine drivers to fill up the oil wells too high, and during running the vibration and oscillation cause the oil to splash over the edge of the box, causing

unnecessary waste. To overcome this, the best method is to fill the oil well with saturated waste, interlacing the oil siphons into it, and oil can then be added to the waste as required. This will prevent the entrance of water and will also prevent waste of oil.

Axle Boxes for Tenders and Cars.—In many cases pads are used for the underside of the journal, plus an additional oil feed by means of siphons arranged in the top of the boxes. The best practice is to use a pad or waste in the boxes and rely on these for the lubrication without any additional oiling from above; this permits doing away entirely with oil grooves in the

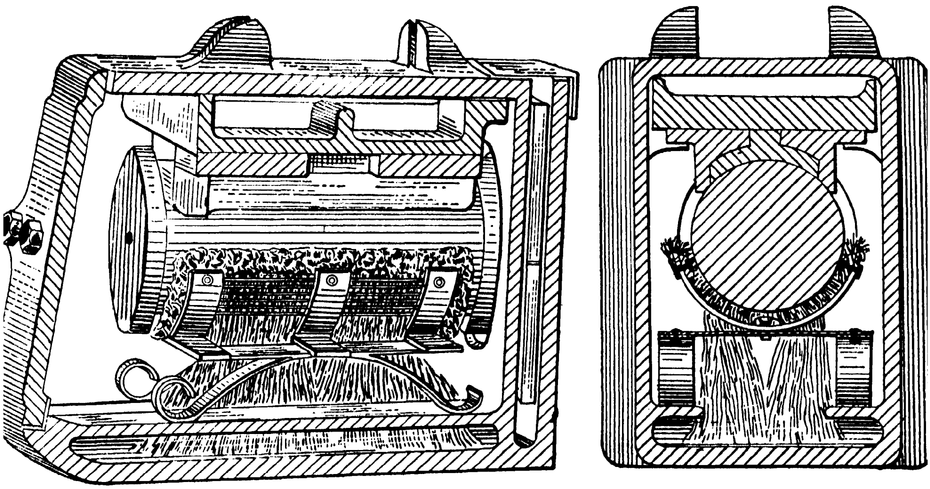


FIG. 92.—Pad oilers.

bearings, so that the whole bearing surface is available to carry the load.

Pad Oilers.—The best known make of these oilers is the Armstrong (Figs. 89 and 92), which has given general satisfaction and is extensively used. The Armstrong oiler consists of a pad on a light frame, supported by resilient steel springs. The pad is so woven that the points of the pile only lightly touch the journal. This pile is made of a special mixture of cotton and wool in order to retain the oil drawn up from the well of the box by the feeders, which should have high capillary powers. The buttons, which are made of lignum vitæ, act as buffers and prevent the pile of the pad from being flattened out and glazed; in this way the capacity of the pad for supplying oil to the face of the journal remains unimpaired for a long period. New oilers should be

dried and soaked in oil for about 12 hr. before being placed in the axle boxes. About 1 pt. of oil should be supplied to each axle box, or sufficient to cover the bottom of the well to the depth of ½ in., and a similar quantity about every 3,000 miles. If the axle boxes are dustproof, and the oilers are kept free from grit and properly fitted, the makers claim that they will last 250,000 miles without repair or removal and guarantee that they will last for 100,000 miles.

Pad oilers like the Armstrong will lubricate the journal however high the speed may be, and the action is unaffected by frequent changes in the direction of rotation.

The use of such oilers results in:

Ample and uniform oil distribution.

Freedom from hotboxes under most conditions.

Less necessity for frequent periodical inspection of axle boxes.

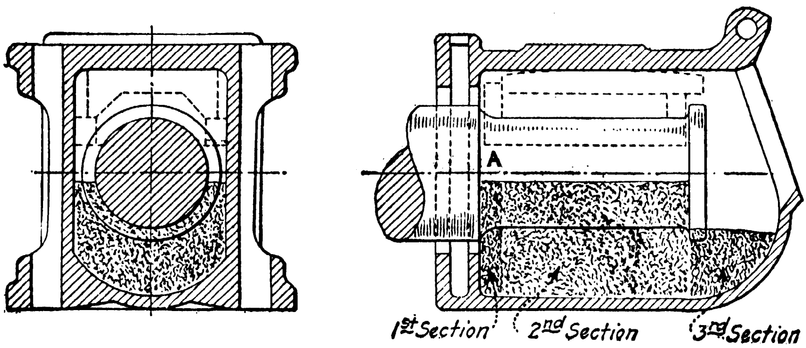


FIG. 93.—Waste oiling.

Reduction in oil consumption and other general lubricating charges.

Waste Oiling.—Good wool waste should be soaked with the proper seasonable kind of oil for at least 48 hr. before being used. The surplus oil should be drained off, allowing sufficient oil to remain so that it will show under slight pressure. If there is too much oil in the waste, the latter becomes too heavy and will fall away from the journal, thus depriving the bearing of lubrication altogether. Well-soaked waste will have absorbed approximately five times its own weight of oil.

The first waste (Fig. 93, *A*) should be moderately dry and packed tightly around the back end of the box, so as to make a guard for the purpose not only of retaining the oil but of excluding the dust. Then the box should be packed with the drained

waste, made into balls, firmly enough so that it will not fall away from the journal when the car runs over crossings, etc., but not so tightly as to squeeze out the oil. The waste should be kept even with the journal, an inch below the edges of the brass. This is most important, as waste packed too high will be caught and carried round, causing a hotbox.

At high journal speeds, say about 300 ft. per minute, the waste is inclined to be pushed over to one side of the box by the friction

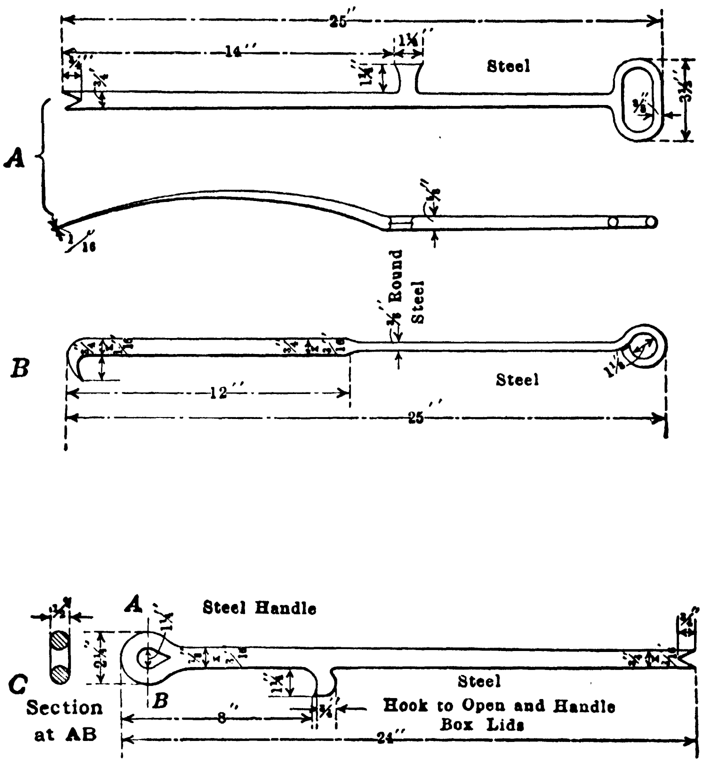


Fig. 94.—Packing tools.

between the journal and the waste and there compressed so tightly that lubrication becomes deficient. There is one type of box that has three compartments divided by longitudinal ribs, thus effectively preventing the waste from moving and ensuring its uniform saturation all through.

The waste in the front end of the box should be as high as the opening and have no thread connection with that underneath the journal. This waste should be placed in the box by hand after the box has been packed. It performs no service other than

to act as a stopper to prevent the waste that is doing the work of lubrication from working forward.

It is important to give some intelligent attention to the waste in the boxes during service, the chief requirement apart from oiling being lightly to loosen the waste packing on either side of the journal for about every 1,000 miles' run, to bring it into good contact with the journal and avoid the hardened and glazed condition which is gradually brought about by contact with the revolving journal. Suitable tools for this purpose and also for packing the boxes are illustrated in Figs. 94 *A*, *B*, and *C*, showing a packing knife, hook, and loosening tool, respectively.[1]

Dust Guards.—Efficient dust guards to prevent the entrance of dust are of the very greatest importance. Too much attention cannot be paid to this matter, as, if dust and grit are allowed to enter, the lubrication can never be perfect, and pad oilers and waste are liable to be choked. The dust trouble is particularly prominent in countries like the south of England, owing to the lime dust.

In the case of newly laid roads, it frequently happens that fine granite dust causes trouble; being very hard and fine it enters the boxes and may cause a great deal of wear.

Inspection and Oiling of Axle Boxes.—Although, as a general rule, it is true that regular and careful inspection of axle boxes is desirable, yet it is also true that there can be too much inspection. As a matter of fact, pad oilers (and this also refers to woolen waste), once they are well fitted and work well, should not be disturbed in any way. An examination every 3 months will, as a rule, be quite sufficient, and at the same time a small quantity of oil may be introduced in the box, assuming that there is no additional oil supply from the top.

The *oil consumption* with waste packing ranges from 500 to 4,000 miles per pint of oil, a good average being 3,000 miles per pint of car oil.

Special Oiling Systems.—Lubrication of axle boxes by means of a circulation system has attracted considerable attention. Several systems have been tried, including a force-feed circulation system by means of a rotary oil pump and also a system consisting of a round disk fixed to the front end of the journal, dipping in the oil in the bottom of the box and lifting it to the

[1] Copied from American Locomotive Dictionary.

top of the box, from which it flows into the bearing in liberal quantities.

It is obviously desirable (particularly in railway practice) to give the journals as liberal a supply of oil as possible. The difficulties are that it is not easy to prevent excessive leakage of oil through the ends of the box and that the entrance of dust and dirt makes the oil dirty and may cause clogging of oil pipes where such exist. Other mechanical appliances have been tried, such as rollers against the underside of the journals, but have not been successful.

It must be kept in mind that whatever appliance is used, it should be so designed that it is not liable to get out of order; *e.g.*, the clogging of an oil pipe or the breakage of one due to vibration will cause stoppage of the oil supply altogether, with disastrous results.

During late years, considerable progress has been made in employing ball and roller bearings for axle boxes; the lubrication of such bearings represents much fewer problems than is the case with axle boxes for ordinary journal bearings.

Connecting Rods and Other Parts.—The brasses in connecting-rod bearings must be let completely together so as to cover the entire surface of the journals and minimize the entrance of dust and grit.

Siphon lubrication is extensively used. For those parts which require only a small amount of oil, trimming pins or trimming plates are used, being a piece of 1/8-in. wire or 1/16-in. plate, which has a hole at the bottom and also at the top, through which are threaded one or two strands of wool, just sufficient for proper lubrication of the motion bars or other parts, where such a small amount of oil is found ample.

It is safer to use siphons than to feed the oil through oil cups where the oil feed is adjusted by means of a needle valve, as a needle valve is more easily choked than a siphon. Figures 95, 96, and 97 show various designs of such oilers.

For reciprocating parts, such as connecting-rod ends, choke or plug trimmings are frequently used (see Fig. 98). This trimming is pushed well into the siphon tube and prevented from dropping right into the tube by a big loop, which rests on the top of the siphon tube. When the engine is running, the oil is thrown up into the siphon tube, and, the trimming being, say, 3/16 in. below

the top, a well or reservoir of oil is always maintained, the oil soaking through the plug trimming and entering the bearing. The plug trimming should preferably end close to the journal, as

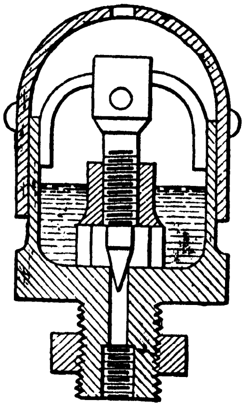


FIG. 95.

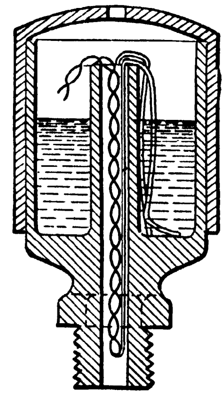


FIG. 96.

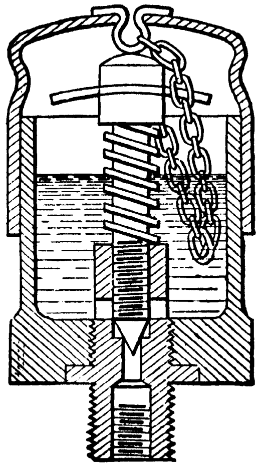


FIG. 97.

Locomotive stationary oilers.

this largely prevents the oil from being wasted by escaping between the brass and the strap. Sometimes a little tube is screwed in here, so as positively to prevent escape of oil. Plug

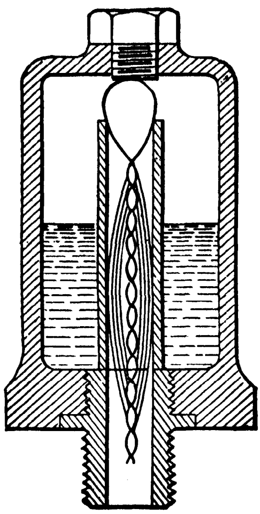


FIG. 98.—Plug (choke) trimming.

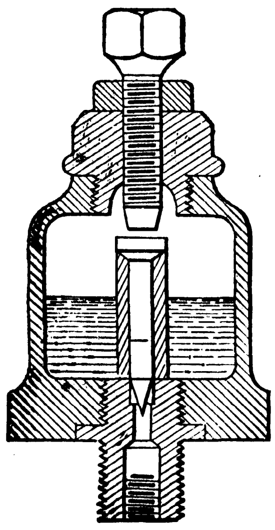


FIG. 99.—Rod needle oiler.

trimmings may be made of copper trimming wire, the wire being wound in the same manner as the yarn in the usual plug trimming. The advantage is said to be that a much heavier oil can be used

than could possibly siphon through the ordinary worsted trimming. Sometimes (in Continental practice) oil is allowed to go direct into the siphon tube through holes at the bottom; this, of course, means waste of oil while the engine is standing. In America and on the Continent, plug trimmings are frequently discarded in favor of small needle valves, consisting of a loose-fitting pin with a head at the top (Fig. 99), the upward and downward motion of the pin being regulated by an adjustable stop in the oil-cup cover.

Another method is to have simply a long thin piece of wire bent over at the top, fitted in the siphon tube, passing through a small fitting screwed into the top of the siphon tube, and having a central opening through which the wire or needle passes down. The difference in diameter between the needle and the opening determines the oil feed.

In oil cups that are entirely enclosed, the cover should have a tiny hole to allow the air to get in as the oil leaves the cup, or the hole in the cover should be plugged up with a piece of cane (which is porous) or a piece of cork with a V groove at the side.

When changing over from an oil largely vegetable or animal in character, it nearly always happens that the siphons and trimmings get more or less choked with deposit due to the change. It is therefore to be recommended, wherever any drastic change in oils is to be carried out, that new trimmings be made for all the oil cups and lubricators.

The consumption of engine oil for the various external parts of a locomotive, including axle boxes, varies considerably according to the size and the method of lubrication. The consumption may be as low as 2 and as high as 8, the average being about 3½ pt. per 100 miles.

When sharp curves are frequent it is desirable to oil the wheel flanges by means of a jet of oily steam. Various forms of lubricators are employed for this purpose; they all endeavor to atomize the oil with a jet of steam, which is then directed on to the wheel flange.

Methodical Oiling.—It is very important that the oiling of the locomotive be carried out in a methodical manner, the oiler going round from one part of the engine to another, oiling always in the same manner of rotation. This is the only way in which he can be reasonably sure of not forgetting some of the parts.

As a matter of fact, lack of attention to this point may be said to be very largely responsible for bearing troubles. This also applies to the attention that should always be given to taking out siphons or trimmings wherever possible when the locomotive has finished the journey. Overfilling of oil holes or oil cups should be avoided, as it is wasteful and does not improve lubrication.

GREASE LUBRICATION FOR LOCOMOTIVES AND CARS

In the United States the use of grease on locomotives has during recent years been given some considerable attention, not

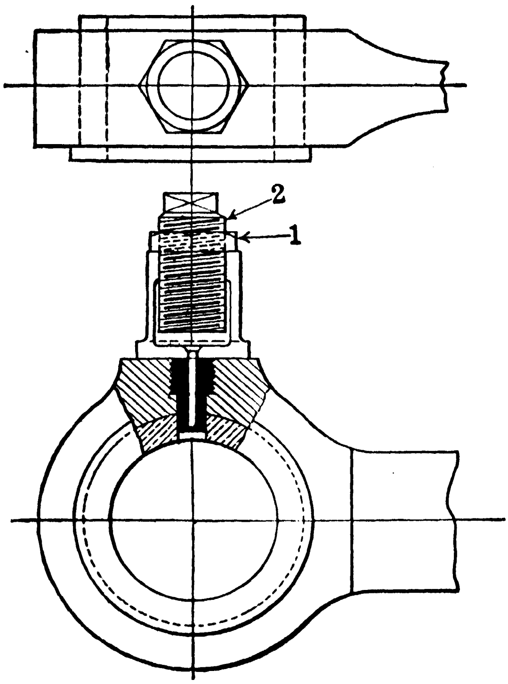


Fig. 100.—Rod grease cup.

only for the connecting rods and coupling rods but also for the axle boxes.

Figure 100 shows the grease-cup arrangement for one of the rods; when the lock nut (1) is loosened, the threaded plug (2) can be given a turn and again locked; the grease gets squeezed into the bearing and is gradually consumed, until the plug is given another turn, and so on.

Figure 101 shows the application of grease to a driving box; the grease is molded to the shape of the collar and placed on the

follower plate (1); the spring (2) pushes the follower plate upward, thus squeezing the grease through the perforated plate (3) shaped to the contour of the journal and kept at a distance of about ⅛ in.

Oil grooves are cut to distribute the grease as shown; the vertical grooves are cut only on the "off" side of the brass, presumably to act as drainage grooves. Through a hole shown on the left, some grease reaches the hub face of the wheel; a similar hole, not shown, is arranged for lubricating the horn plates.

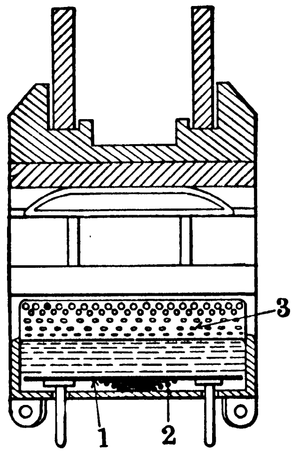


FIG. 101.—Driving-box grease lubrication.

It is stated by the makers of these grease appliances that the grease recommended for the axle boxes must not get sticky when worked between the fingers and that when smeared with a penknife on a piece of white paper small bubbles of water must appear on the surface. The author has no personal experience with these greases; they are probably rather soft low-melting-point greases somewhat similar to the English railway-wagon greases mentioned below and containing a certain amount of water to bring about emulsification, so that the journal when revolving may continue to abrade or melt the grease.

It is obvious that whatever claims may be substantiated in the way of "economy" and ability to stand up to severe conditions, the amount of power lost in friction is considerably increased with grease lubrication and also the wear.

An advantage with grease lubrication is that the starting friction is lower than with oil on account of the thicker film between the surfaces.

Some tests were carried out in 1904 at the Saint Louis Exposition on locomotives, using grease and oil. A consolidated-type locomotive, 22 by 28 in., eight-wheel coupled, two wheels in front (2–8), developing a maximum power of 1,000 to 1,100 hp., showed a frictional loss as follows:

Oil at 15 miles per hour: 61 hp.
at 30 miles per hour: 107 hp.
Grease at 26.6 miles per hour: 224 hp.

A Pennsylvania consolidated-type locomotive, developing a maximum power of 1,000 to 1,100 hp., consumed in friction alone when using grease throughout:

With grease at 15 miles per hour: 132 hp.
at 30 miles per hour: 224 hp.

It was demonstrated that wear of axles and crankpins was greater with grease than with oil and that there was not much difference in the cost of lubrication, the consumption with grease being approximately 450 miles per pound of lubricant.

Outside the United States grease has not been favored for locomotive lubrication; in Europe oil is used everywhere in preference to it.

In Great Britain grease is, however, still used for lubricating colliery trucks and freight wagons, but this practice is rapidly dying out in favor of oil.

The grease is placed in a cavity formed in the top of the axle box. Large openings in the bottom of this cavity communicate with similar openings in the brass, and under the influence of frictional heat the grease gradually melts and lubricates. The friction is high; the boxes are often neglected, lids are torn off, and the grease cavities contaminated with dirt, water, etc. Altogether the results are such that the sooner this form of lubrication is done away with in favor of oil lubrication the better.

On page 27 will be found some information about the manufacture and constituents of such railway-wagon greases.

Railway Oils.—The character of railway oils is governed to a large extent by the climatic conditions. In the tropics the oil is exposed to very high temperatures during the day and quite low temperatures during the night. Long-distance trains going from a warm low-lying country into a cold mountainous district will find themselves exposed to widely varying temperature conditions during their journey. In temperate climates the same conditions exist except that the differences between the day and night temperatures are smaller; still, the variation in temperature may be quite considerable. For example, the Scottish express trains running between London and Scotland will meet temperatures in the North very appreciably lower than those in the South.

These conditions call for oils with low setting points in order that they may feed as uniformly as possible and with certainty through the oil siphons and other feeding appliances.

On the other hand, once the oil has entered the bearing surfaces it is exposed to considerable pressure and high temperature, so that it must possess great oiliness at the bearing temperature. In brief, railway oils must have viscosities that are not unduly influenced by great variations in temperature. The oils that best satisfy these requirements are mixtures of nonparaffin-base mineral oils with setting points in the neighborhood of 0°F. mixed with from 10 to 25 per cent or even more of a suitable fixed oil. Mineral oil of the character described will give fluidity in the cold, and the admixture of fixed oil has the effect of maintaining great oiliness and viscosity at high temperatures.

The admixture of fixed oil serves another purpose in the case of locomotive-engine oil, in that it prevents the oil from being washed away from the bearing surfaces by the steam which escapes from the piston rod and valve-rod gland, the condensed steam producing a "lather" on the guides and other parts.

The setting points required for the blended oil can be determined only on the road, although siphoning tests may be carried out in the laboratory indicating the siphoning and the capillary power of the oil at different temperatures, including the lowest temperatures to which the oil will be exposed during service. Such siphoning tests are not much used by railways, and yet they are of the greatest importance.

Oils differ very considerably in their ability to siphon, and, furthermore, the quality of wool on the market varies very considerably in its siphoning qualities. In the case of siphon oilers, the wool that will give the greatest siphoning effect for the class of oil in use is the most desirable. In the case of pad oilers, which are fixed below the axles and lift the oil from the bottom of the box, the ability of the pad and its feeders to draw the oil and hold it is most important. It will be found that the quality of wool required for the two purposes is different. Wool or cotton that will lift the oil a considerable distance and hold it there will not easily deliver it to the journal, nor will it have good siphoning qualities when used in a siphon oil cup.

As regards the viscosity of railway oils, it is always desirable that it should alter as little as possible per degree Fahrenheit.

As a rule, the more fluid the oil the quicker will it feed through the lubricating appliances; and consequently if the oil varies greatly in viscosity with a varying temperature, the feed will be irregular and wasteful. When comparing oils for change in viscosity due to increase in temperature, the oils least affected at the bearing temperatures are the free-flowing vegetable or animal oils, while mineral lubricating oils made from either paraffin-base crudes or asphaltic crudes are distinctly inferior in this respect. When the running temperatures are low, approaching freezing point, the comparison may fall out differently, as most vegetable and animal oils (as well as paraffin-base lubricating oils) have a poor cold test, whereas asphaltic-base oils still flow freely.

The selection of the right quality of vegetable or animal oil is very important, because unsuitable fixed oils usually become acid during use and have a strong tendency to oxidize and produce gummy deposits. The acidity has an effect on the bearing metal, and that, in connection with the gumminess produced by the oil, attracts and fixes the dust and dirt that enter the bearing. As a result, the oiling pads or oiling waste or the oil siphons become choked and more or less inoperative, because of the deposit.

The fixed oils used for compounding locomotive-engine oils may be rape oil, olive oil, or whale oil or mixtures of these; rape oil and whale oil are usually used in the form of blown oils, blown to a viscosity of 400 to 720 sec. Saybolt at 212°F., and the percentage ranges from 10 to 25, the same as for marine-engine oils; in fact, the character of the oils is very similar.

Car oils are usually dark lubricating oils, containing less than 3 per cent of asphaltic matter and preferably compounded, although not to the same extent as locomotive-engine oils, as the bearing pressures that they have to withstand are much less.

Car oils are preferably compounded with 8 to 12 per cent of animal oil (blown vegetable oils are apt to clog the pads). They are often used straight, *i.e.*, not compounded, on account of the lower price per gallon.

The specifications on page 291 are typical of locomotive-engine oils and car oils.

In exceptionally cold climates lower setting points may be required; and when locomotive bearings are abnormally loaded,

LOCOMOTIVE ENGINE AND CAR OILS

Oil	Specific gravity	Viscosity number*	Viscosity, centipoises at 50°C.	Per cent of compound	Setting point, degrees Fahrenheit	Color
Locomotive engine,						
summer grade...	0.920	7	26	15 to 25	10	Dark red
winter grade....	0.920	6	20	10 to 20	0	Dark red
Car, summer grade	0.930	8	38	8 to 12	10	Black
winter grade....	0.930	7	26	5 to 10	0	Black

* See table, p. 57.

a greater percentage of compound than recommended above may be needed, even to the extent of using pure rape or pure castor oil. Pure castor has here the advantage over other fixed oils of possessing an excellent cold test, which under great variations in temperature is of great value.

CHAPTER XX

ELECTRIC STREET- AND RAIL CARS

Streetcars are nearly always driven by electric motors but are occasionally operated by cables traveling below the streets, *e.g.*, the cable trams in Edinburgh.

The important parts requiring lubrication are the axles, the motor, and the gearing.

Axle Boxes.—The construction and lubrication are often very similar to railway practice. One meets all sorts of combinations of siphon oiling (from the top), pad oilers, or oily waste packing (from below), the development being distinctly in favor of the last-mentioned oiling methods.

The Armstrong and other pad oilers are widely used, but unfortunately many oil wells are made too small, so that it is difficult to fit the pads, and the wells contain too little oil.

A very unsatisfactory combination of grease and oil lubrication is not infrequently used. The oil is fed from below, and the grease, filling a cavity in the brass, acts as reserve lubricant. The trouble is that the grease becomes softened by the oil film on the journal and in time gets worked into the pad oiler below the axle, choking the pad and making it inoperative.

With grease alone, the friction and wear are much greater than with oil, and the necessary period of oiling and inspection of the cars varies from once a day to twice a week, whereas with oil an inspection once every 2 to 6 weeks represents current practice.

The axle boxes are usually fitted with dust guards. This is important, to keep out not only the dust but also water, as, on rainy days and when the tracks are not properly drained, the wheels throw the water about; and if it gets inside the bearings in any quantity, trouble is sure to follow.

Motor Bearings.—Ring oiling is not uncommonly employed, and when suitable shapes of rings are employed (see "Ring-oiling Bearings," page 162) the rings will run at such a speed that no oil

spray is formed, and yet sufficient but not too much oil will be conveyed to the journal.

Much trouble has, however, been experienced with ring oiling on electric cars, the oil escaping from the bearings and getting on to the commutator and rotor.

Pad oilers are gaining in favor both for motor bearings and for suspension bearings, as they are very reliable in feeding the oil and do not overlubricate the journal. The pad must be placed so that it rests on the journal in a position where the oil can easily wedge its way in between the bearing surfaces (Fig. 102). From

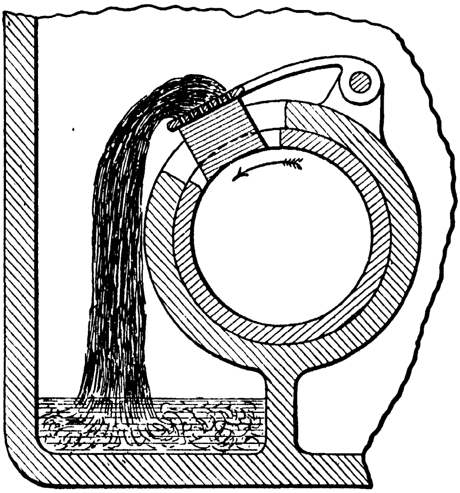


FIG. 102.—Pad oiler.

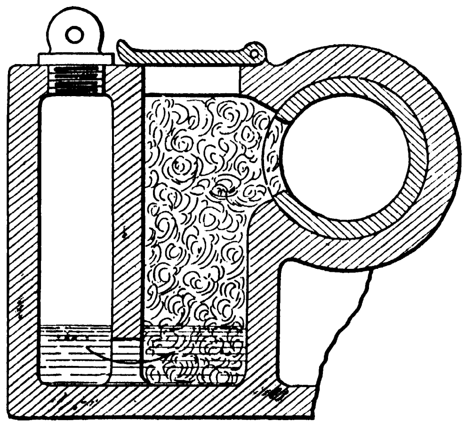


FIG. 103.—Waste oiling.

the pad a number of woollen siphon strands reach down into the oil well, which may hold a large amount of oil, or, if it is small, the oil should be fed continuously to the well from an oil cup placed in a suitable position.

Oil-soaked waste is also used to some extent, feeding through an opening in the side of the brass, as shown in Fig. 103. The opening may be rectangular, with all sides well chamfered on the inside where the oil is to enter the bearing, and from each corner a shallow oil groove has been found advantageous to distribute the oil, on account of the rather sparing oil supply.

Oil is added at intervals to the oil-soaked waste in the way indicated; in one case 1 pt. of oil had to be added every 120 to 160 miles for a 5¼- by 10-in. journal running 1,100 to 1,600 r.p.m., the weight of the rotor being 2 tons.

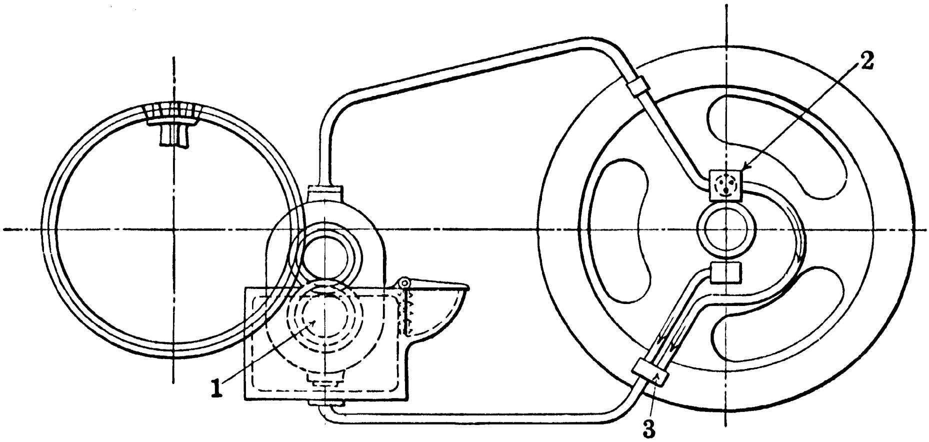


FIG. 104.—Diaphragm-circulation oiling.

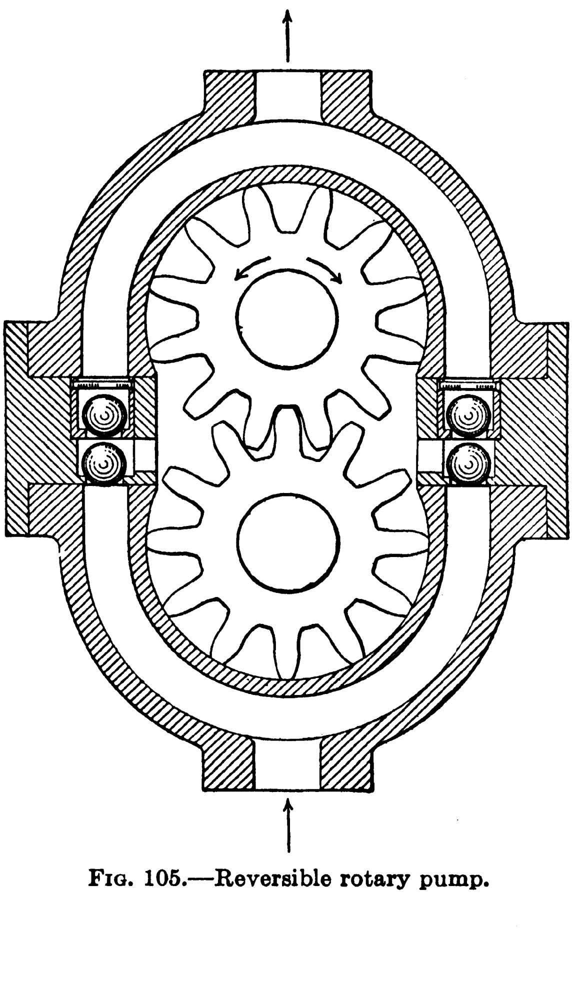


FIG. 105.—Reversible rotary pump.

An interesting method of circulation oiling has been used for the motor bearings on a south-of-England electric railway, as shown in Fig. 104. The oil pump (1) pumps the oil in the same direction independent of the direction of its rotation, as will be seen from the detail drawing (Fig. 105). The oil is forced to the diaphragm plate (2) which has one, two, or three 1-mm. holes, through which a small amount of oil is constantly delivered to the bearing, the greater portion continuing its way to the suction-joint box (3), where it joins the return oil from the bearing and finally reenters the oil pump. Each motor bearing has its own independent pump-supply, delivery, and return pipes.

The wear of motor armature bearings on British streetcars ranges from 5,000 to 50,000 miles per 1/16 in. vertical wear, the wear of the suspension bearings being rather less; the average life of motor bearings appears to be 10,000 to 12,000 miles.

The reason for such large wear as compared with stationary motors is the effect of fine hard grit and dust (wear from pavement, etc.) which are whirled up by the wheels and enter the bearings.

During late years, considerable progress has been made in employing ball and roller bearings both for motors and for axle boxes.

Gear Wheels.—Most gear wheels are enclosed in a casing and use some kind of thin gear grease. The results are always inferior to those obtained with gear oil, but of course the gear case, if oil is to be used, must be as oiltight as possible.

With grease or grease and oil, the life of the gear wheels may be from 50,000 to 200,000, whereas with oil the gears last considerably longer.

The pinion wheels do not last so long as the gear wheels, but also here the use of oil is conducive to longer life.

Oils.—The oils used for lubricating the axle boxes of electric streetcars and railway cars are usually lower in viscosity than those used in railway practice, because the bearing pressures and conditions generally are not nearly so severe. Bearing oils 3 and 4 (see page 135) represent oils that may be recommended for electric streetcars, and bearing oils 4 and 5 are recommended for electric railway cars. All of these oils should preferably be compounded with not more than 10 per cent of a nongumming

animal oil, and in cold climates a low setting point would be required.

The oils for motor and suspension bearings should be of a rather higher viscosity, as they are exposed to high temperatures (commutator heat) or pressure (from pinion wheel).

Bearings oils 5 or 6 may be recommended and may with advantage be compounded when the conditions are severe.

As to gear lubricants, the same oils as are used for the motor and suspension bearings can be used when the gear case is reasonably oiltight. When a more viscous lubricant is required, mixtures of oil and gear grease in suitable proportions, so that the mixture is not unnecessarily heavy, will form the best solution.

Wheel-flange Lubrication.—For electric locomotives which have to negotiate many curves, *e.g.*, the electric locomotive service through the Saint Clair Tunnel, Switzerland, wheel-flange lubricators have given excellent service. The oil is contained in an airtight receptacle of 1-qt. capacity, whence it is led to the wheel flanges by pipes and sprayed upon the flanges by jets of air. The air is supplied through a $\frac{1}{4}$-in. pipe, which is connected to the oil receptacle above the surface of the oil. A branch of this pipe is connected to the oil-delivery pipe which leads to the flanges. The air is controlled by an electric push button, so that the lubricant is applied only when needed, as on curves. This apparatus has been in successful operation since July 10, 1910. The six electric locomotives to which it has been applied haul 1,000-ton trains up and down 2 per cent gradients on which flange wear has been rather heavy, owing to the many curves and the rather low center of gravity of the locomotives. Lubrication of the flanges has so improved conditions that 50,000 miles and more are now run between wheel tire turnings. This means that the wheels can be removed for turning at the same time that the armature is removed for commutator dressing. The former mileage made between tire turnings was from 12,000 to 25,000 miles. Filtered reclaimed armature-bearing oil is the lubricant used.

CHAPTER XXI

TRANSMISSION SHAFTING

The long main lines of shafting used for power transmission are called "line shafting." Countershafting is driven from the line shafting and operates the various machines by fast and loose pulleys or by clutches.

The speed of shafting ranges from 120 to 450 r.p.m.; the diameter of line shafting usually ranges from $2\frac{1}{2}$ to 6 in.; of countershafting, from 1 to $2\frac{1}{2}$ in.

Many bearings on countershafting and small-diameter line shafting are hand oiled or oiled by glass-bottle oilers. Line-shafting bearings are seldom hand oiled; they are usually bottle oiled, and modern shafting is frequently ring oiled. Ball and roller bearings are also coming into prominence for quick-speed line shafting.

Heavy large-diameter shafting bearings, *e.g.*, many second-motion shaft (jackshaft) bearings, develop so much heat that they can be kept cool only by a circulation-oiling system.

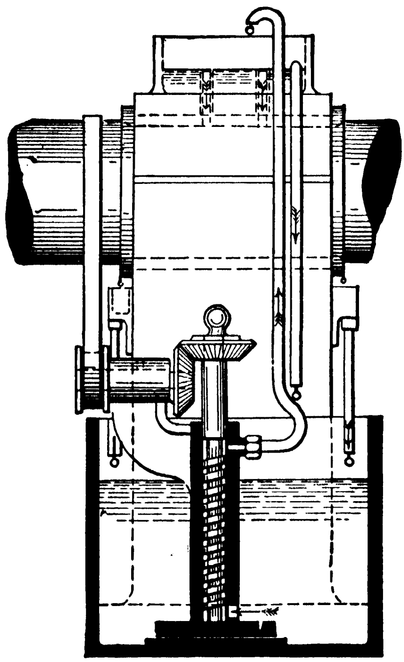


FIG. 106.—Screw-circulation oiling.

Figure 106 shows a simple form. The screw can be lifted right out for examination by taking hold of the knob.

Figure 107 shows a more elaborate system with three oil feeds from the oil box. The drawing will need no explanation.

The power required to drive the line and countershafting in a mill or shop is always a considerable percentage of the total load. In textile mills it ranges from 20 to 60 per cent; in engineering workshops, from 20 to 75 per cent. Whether more or less

machines are in operation, the shafting load is always of the same magnitude, and it is not too much to say that in most existing factories or works an average of 10 per cent could be saved in the shafting load by introducing better lubricants, and another 10 per cent by regular attention to keeping the shafting in perfect alignment. Losses from poor alignment and from unsuitable oils frequently occur simultaneously. Poor alignment often means

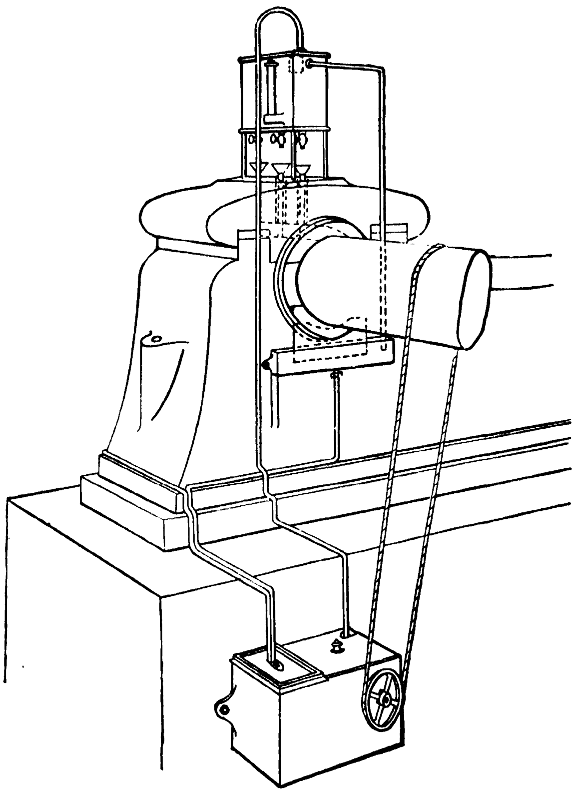


FIG. 107.—Pump-circulation oiling.

that certain bearings heat because of the extra load; instead of the bearings' being adjusted, the oil gets the blame, and a more viscous shafting oil is introduced, which "cools" the bearings inclined to heat and at the same time adds 10 to 25 per cent of extra fluid friction to all the other bearings. If bearings are kept in good alignment, low-viscosity shafting oils can be used, and a considerable saving in power obtained (see remarks, page 326, regarding shafting in textile mills).

Where electric driving is employed, it is a simple matter to take the shafting load every 3 or 6 months, as a check on the

efficiency. With steam plants, the indicated horsepower may be recorded, or the number of revolutions of the flywheel and the time taken before it comes to rest from full normal speed, after steam has been shut off.

Shafting bearings should be provided with save-alls to prevent dripping of lubricant. Oil creeping along the shaft, when it does occur, is usually only toward one side of the bearing and may be overcome, as shown in Fig. 108, by an oil thrower (1) and splash guard (2). The oil drops from the splash guard into the save-all (3). (As regards ring-oiling bearings, see page 161.)

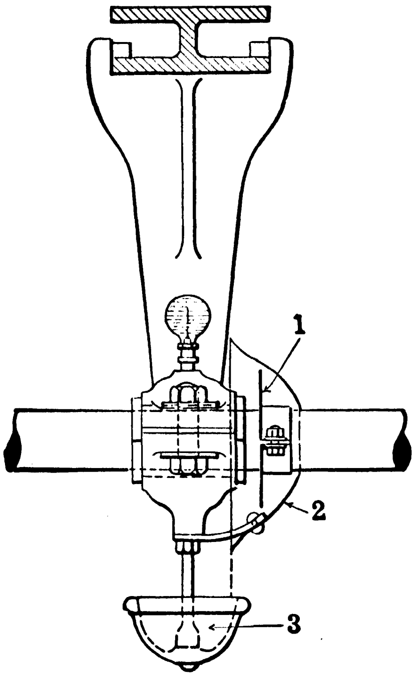


FIG. 108.—Shafting oil thrower.

Ball and roller bearings save a great deal of power; a type of roller bearing very suitable for line shafting is the Hyatt flexible roller bearing (Fig. 49, page 181) which gives a coefficient of friction of 0.005 to 0.008, whereas ball-shafting bearings give a coefficient of friction of 0.002 to 0.003. Good alignment is essential with ball and roller bearings, more so than with plain bearings, an exception being the Skefko ball bearing. The following figures indicate the coefficient of friction that may be expected for different methods of lubrication in connection with shafting bearings:

	Coefficient of Friction
Ball bearings	0.002 to 0.003
Roller bearings	0.005 to 0.008
Ring-oiling bearings	0.010 to 0.015
Bottle oiling, siphon oiling	0.02 to 0.04
Hand oiling	0.04 to 0.15

The great savings in power that follow the introduction of high-class shafting bearings is better realized on the Continent of Europe than elsewhere; in Great Britain and the United States conditions of shafting are much behind Continental practice.

Lubrication.—Most shafting bearings are lubricated by oil; as mentioned elsewhere, shafting in weaving sheds is frequently lubricated by grease applied through gravity grease cups, spring grease cups, or applied direct to the shaft. Stauffer cups are not used, because they must be given a turn every day or two, while the other methods are more or less automatic in action and require attention only at long intervals.

The waste in power by applying grease, as compared with oil, ranges from 5 to 20 per cent of the shafting load, according to the fluidity and quality of the grease and the speed of the shafting.

The better the lubricating system the lower viscosity oil can be used, and the lower the friction.

For hand oiling, oils compounded with, say, 5 per cent of a nongumming fatty oil will last longer and give better results than

LUBRICATING CHART FOR SHAFTING BEARINGS

Shafting oil	Viscosity in centipoises at 50°C.	
Bearing oil 2*.....	8	For most moderate- and high-speed shafting and countershafting in good alignment and condition and with reasonably good lubricating appliances This oil is usually too thin for hand-oiled bearings
Bearing oil 3......	10	For slow- or moderate-speed light and medium shafting and countershafting in good or moderate condition and with good or moderate lubricating appliances Also for hand-oiled bearings on countershafting
Bearing oil 4......	13	For slow- or moderate-speed heavy shafting
NOTE.—For lubricants for ball and roller bearings, see page 193.		
Shafting greases...	..	Grease should be of as light a consistency and as low a melting point as practicable, without incurring undue waste of lubricant The mineral oil used in the grease should be of viscosity similar to that of the oil that would prove suitable if the bearings were arranged to use oil instead of grease

* For bearing oils, see p. 135.

straight mineral oils. For bottle oilers, straight mineral oils should be used to ensure the needles' keeping clean and in working order. Oils for ring-oiling bearings and ball bearings should also be straight mineral.

The chart on page 300 is a rough guide for selecting the correct grade of shafting oil.

CHAPTER XXII

MACHINE TOOLS

Machine tools are machines such as lathes, shapers, and boring, drilling, milling, planing, and grinding machines, the speeds ranging from quite low on large lathes and planers to very high—up to 10,000 to 30,000 r.p.m.—for modern grinders.

A great many bearings on most machine tools are hand oiled, the speeds or pressures being low. The oil holes should preferably be protected by a cover. Figure 109 shows a typical oil-hole cover; the lid (1) is turned, disclosing the oiling hole (2); the lid, by means of an internal spring, may be made to turn back

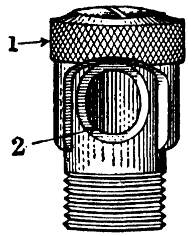


FIG. 109.—Oil-hole cover.

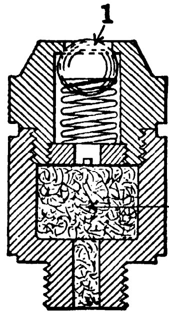


FIG. 110.—Ball valve and felt chamber.

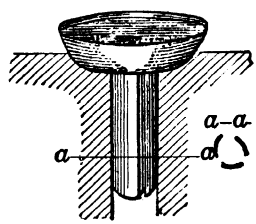


FIG. 111.—Oil-hole protector.

Hand-oiling arrangements.

automatically and cover the hole after the oiling operation. Figure 110 shows a hand-oiling arrangement with ball valve (1) and felt chamber (2). Felt, wool, or worsted yarn may be used in the chamber and serves to feed the oil more uniformly to the bearing in between oilings. With a rise in temperature more oil is liberated, so that such an arrangement is a great improvement over the ordinary oil hole without felt.

Figure 111 shows a simple oil-hole protector, consisting of a cup, the shank of which is split in three parts which grip the oil hole as the cup is pressed into position. The cup and shank are filled with felt, which acts in the same way as the felt in Fig. 110.

In many modern machine tools, felt-pad arrangements are made use of to a considerable extent. Figure 112 shows an

arrangement used by Brown and Sharpe for the bearings of internal-grinding spindles. The oil soaks through the felt and

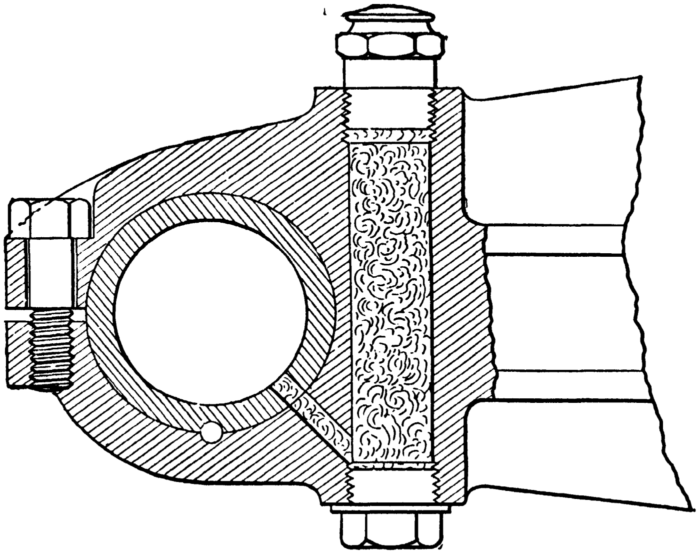


FIG. 112.—Felt-oiling arrangement for grinder spindle.

enters the bearing through the passage shown.

In many bearings large recesses are cored out around the spindle boxes in the middle and fitted with felt pads, which are pressed gently against the revolving spindle by means of light feather or spiral springs.

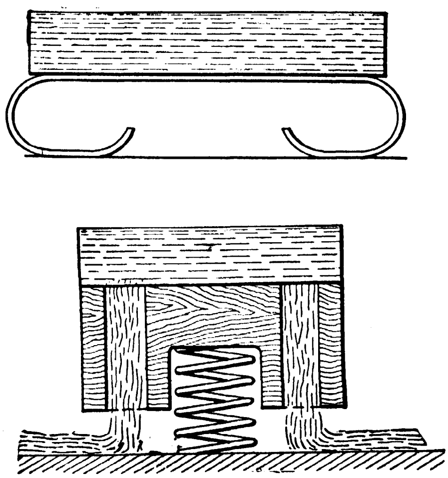


FIG. 113.—Spring felt pads.

Figure 113 shows two types of pads; when in use they are both placed below the spindles in a well partly filled with oil, which is replenished from time to time through an oil-filling hole at the top communicating with the oil well. Right- and left-hand spiral grooves, as shown in Fig. 114, are excellent for distributing the oil toward the bearing ends, where fine V threads on the spindle cut in the opposite direction tend to prevent leakage and have proved very efficient in this respect.

Bearings that require a fair amount of oil may be supplied by small siphon oil cups or drop-feed oilers; occasionally, ring-oiling

bearings are employed. In some recent designs a circulation-oiling system is employed, a pump delivering the oil to a distributing box, whence oil is guided to the various bearings and gears and finally returns to the pump reservoir. Grease is seldom used for machine tools, except in ball bearings, which are now widely used, especially as vertical thrust bearings for drill spindles, heavy revolving tables, etc.

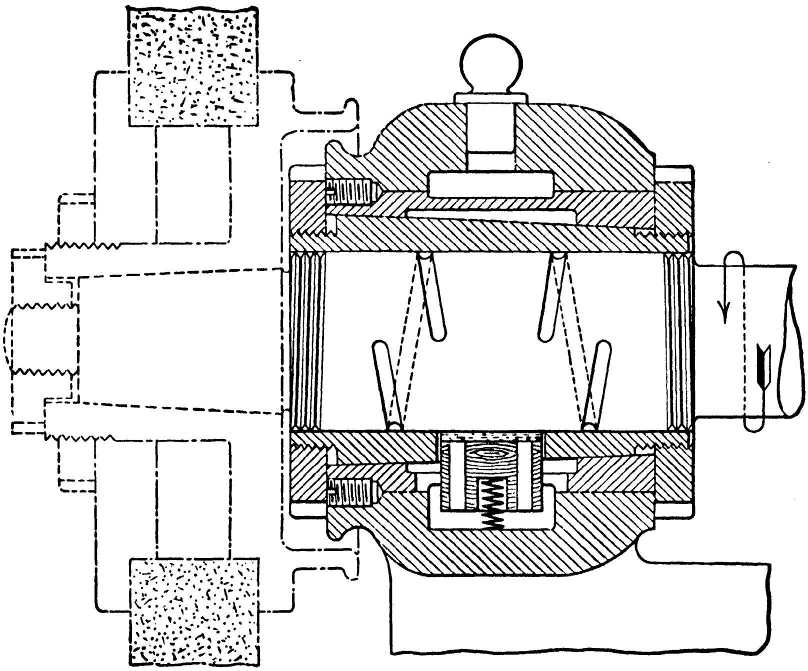


FIG. 114.—Spiral oil grooves for grinder spindle.

The lubrication of lathe saddles, ram slides of shaping machines, and flat or V-shaped slides of planing machines is receiving more attention nowadays. Instead of the surfaces' merely being flooded by an oilcan, most of the oil being wasted to no good purpose, some modern machines have felt-pad insertions in the sliding member. The felt pads are kept soaked with oil, being hand oiled through oil passages from above, and keep the large surfaces economically and fairly well lubricated. In some V-grooved slides, V-shaped wheels are placed in the stationary slides; the wheels are partly immersed in oil and are forced gently against the moving slide which they lubricate. The felt-pad arrangement is probably equal to if not more efficient than the revolving wheels.

Apart from high-speed machine tools, the majority of bearings in machine tools are only poorly lubricated at the best of times, and the coefficient of friction is high. Slightly compounded oils are therefore preferable to straight mineral oils, as they have greater oiliness. The low-viscosity oils, which are (or ought to be) used for high-speed tools like grinders, need not be compounded, as the friction depends upon the viscosity of the oil and not on its oiliness.

Exposed in thin films to the oxidizing influence of air and fine metallic dust, the oil which invariably creeps all over the machine tools in time oxidizes and stains or tarnishes the bright surfaces, particularly in machine shops exposed to bright light or sunlight.

In all mineral oil there are certain complex unsaturated hydrocarbons, coloring matter, etc., which are easily oxidized and which are the cause of the brown, thin, tenacious films just referred to.

Pale mineral oils are less apt to cause tarnishing than dark-colored oils, and it is a great help to have a small percentage of animal oil, say 6 per cent of lard oil, mixed with the mineral oil. The admixture of animal oil has a marked effect in preventing the oxidized matter from forming a film and makes it quite easy to wipe the surfaces clean.

An admixture of a vegetable oil will have the opposite effect; it helps to cement the oxidized matter together and makes it more difficult to keep the bright surfaces on the machines clean.

LUBRICATION CHART FOR MACHINE TOOLS

Oil of Three Viscosities Are Required as Follows:

Oil	Viscosity, centipoises at 50°C.	Type of machine tools
Bearing oil 1*....... (Straight mineral)	4.5	For very high-speed machines, as grinders
Bearing oil 2........ (Preferably pale and compounded with 6 per cent of lard oil)	8	For all moderate- or high-speed machine tools of every description, except grinders
Bearing oil 4........ (Preferably pale and compounded with 6 per cent of lard oil)	13	For all slow- or moderate-speed, heavy machine tools, for gear chambers, etc.

* For bearing oils, see p. 135.

CHAPTER XXIII

TEXTILE MACHINERY

The textile industries, comprising the cotton, woolen, worsted, silk, rayon, flax, hemp, and jute industries, are all highly specialized and employ such a variety of machinery that it is impossible inside a few pages to give even an outline of the principal types and their uses.

Characteristic of most of the machines is that the amount of power actually used in doing useful work, *i.e.*, in handling the fibers or material itself, is small and that by far the greater portion of power is consumed by the friction of numerous spindles or shafts often revolving at high speeds and usually only lightly loaded.

Great improvements have taken place so far as the mechanical construction and lubricating arrangements are concerned, and the author will endeavor in the following pages to point out some of the important features. While considerable attention has been paid to the selection of suitable oils, yet very great power reductions can be accomplished in practically all existing mills by the introduction of such oils as will be mentioned later on.

The subject will be divided into four sections, *viz.:*

1. Preparing.
2. Spinning.
3. Weaving.
4. Bleaching, Dyeing, Printing, Finishing.

PREPARING

Openers and Scutchers (Used for Cotton Only).—Openers and scutchers are very similar in action; they open and loosen the fibers of cotton by quickly revolving beaters; the cotton fluff thus formed is blown a certain distance and again gathered together, forming a soft thick sheet of cotton called a "lap." In this process the cotton fibers are cleaned from dirt and grit, passing first through the openers and next through the scutchers.

There are quickly revolving spindles in these machines, the lubrication of which is important. By feeling these bearings, an expert can always get an idea of the quality of the spindle oil used in a mill; if they run excessively warm, the oil in use is probably too viscous, assuming, of course, that the bearings are in good condition mechanically.

The high-speed bearings are either oiled by bottle oilers or, preferably, ring oiled.

The room in which the openers and scutchers are placed is called the "blowing room," or "scutching room."

Washing and Drying Machines (Used Only for Wool and Worsted).—Wool-washing and -drying machines do not present any lubrication features of interest, except that in some mills hydroextractors are used for "whizzing" the wool before it passes into the drying machines for the final drying.

These hydroextractors are of the same type as those used for recovering oil from waste (Fig. 231, page 612), and unless they have ball bearings or Michell bearings they require oils of great oiliness—much more viscous than the spindle oils used in the mill. Hydroextractors are usually driven direct by a small steam engine or steam turbine.

Preparer Gill Boxes (Used for Wool, Worsted, Flax, Hemp, Jute, and Waste Silk).—These machines comb open the fibers, lay them parallel, and deliver them in the form of a continuous "end," or lap. The material always has to pass through several sets of gill boxes.

The last preparer gill box in the series is called the can gill box and is shown in Fig. 115. The lap (1) enters the back rollers (2) and is drawn between the front rollers (3) and delivered through the slowly revolving funnel (4) as a continuous sliver into the can (5). Between the front and back rollers the fibers are combed by the fast-moving fallers (6) which rest with their ends on slides and are pushed to the right by means of square-threaded screws; they fall at the end and are returned quickly by bottom screws (revolving in the opposite direction) to be raised again into position just behind the front rollers.

The fallers, slides, screws, etc., wear rather quickly, and good lubrication is therefore extremely important, particularly when working with dusty fibers, such as jute and hemp. The dust, which is composed of earthy particles, also small pieces of

woody and fibrous matter, contaminates the oil on all rubbing surfaces.

If when leaving the gill boxes the fibers (such as wool) go to the carding machines, they must be oiled. The oiling should not be done in the first, second, or third gill boxes but preferably in the can gill box. One method of oiling is shown in Fig. 115.

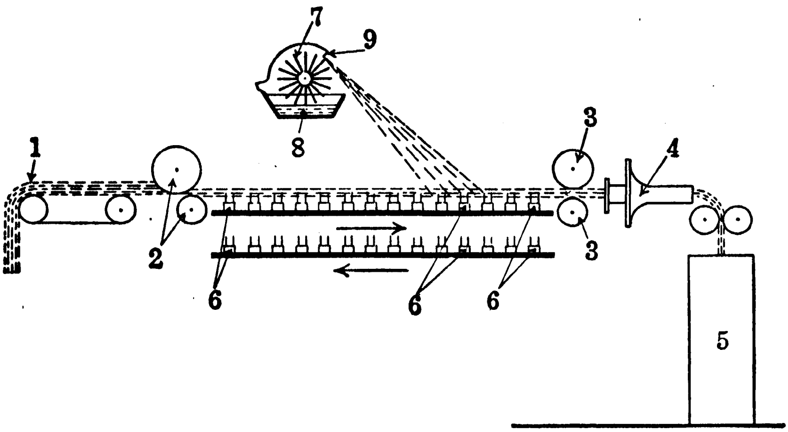


FIG. 115.—Preparer gill box.

A circular brush (7) revolves in the oil trough (8). When the bristles of the brush pass the blade (9) they shower or spray the hot oil on to the fibers of the wool as they pass through the machine.

Carding Machines (Used for All Short Fibers, Not for Long Worsted and Long Silk).—The carding operations remove all impurities and arrange the fibers parallel, delivering the material in the form of sliver.

The soft laps coming from the blowing room enter the carding machine and are broken up by the revolving cards, being delivered from a large carding drum to smaller carding drums, which return the fibers to the main drum; finally, the fibers are removed in the form of a thin veil from the last drum by means of a quickly oscillating stripping comb. The veil is gathered together through a trumpet, passes a pair of rollers, and is delivered as sliver into a card can.

The bearings for the stripping comb are placed in so-called "stripping-comb boxes," which contain a bath of oil and in which cams operate and give motion to the stripping comb. These stripping-comb boxes are always rather warm and indicate the

quality of the spindle oil. The numerous bearings on the carding machines require to be well oiled. Several of the spindles supporting the smaller carding drums have an endwise oscillating motion, tending to scrape off the oil film.

There are usually two or more sets of cards before the sliver is passed on to the drawing department.

Short wool does not leave the cards as sliver, but, before going to the drawing frames, it is passed from the cards straight into so-called "condensers"; the wool enters these as a thin soft sheet and is divided into a number of strips, which are rolled into coarse threads, suitable for coarse spinning, which is the next operation.

Combers (Used for All Long Fibers, Only Rarely for Cotton).—Long wool, worsted, flax, and other long fibers are not carded but pass through combers. There are many types of combers, but the object in them all is the same, *i.e.*, to straighten the fibers and separate the short from the long ones.

Most parts of these machines, such as revolving tables and drawing-off rollers, revolve slowly and require a rather viscous oil, but the "dabbing brushes" have a quick motion and should preferably use thin spindle oil. Modern dabbing motions are enclosed in a chamber containing oil to ensure continuous lubrication, and a speed of 800 to 1,200 dabs per minute can be obtained without unreasonable vibration.

The slowly revolving tables—"circles"—are often supported by balls placed in ball races. These races become very hot when the circles are steam heated, and the oil will carbonize and gum unless the oil manufacturer has kept this condition in mind and selected a "noncarbonizing" oil. Some circles are supported by large rollers, which revolve and dip into oil reservoirs and are thus kept continuously oiled.

Drawing Frames.—The drawing frame receives thick "slivers" of fibers and attenuates them by the so-called "drawing" operation.

The frame consists essentially of several sets of rollers, each successive pair revolving at a greater speed than the previous pair. The top rollers are weighted, and the bottom rollers fluted to grip the fibers tightly.

When drawing material like wool or worsted the rollers are heavily pressed together, and a specially viscous oil is required;

with cotton the rollers are not so heavily loaded, and they are easier to lubricate. Care must be taken not to overlubricate, as if the oil gets on the rollers it will produce oil stains on the yarn. The bearing keeps for the roller bearings should preferably be fitted with flannel layers inside, which have the effect of holding and distributing the oil all over the bearing surfaces and keeping the dust out.

Slubbing, Intermediate, and Roving Frames.—Slubbing, intermediate, and roving frames are used for producing coarse thread from the sliver coming from the drawing frames, the sliver

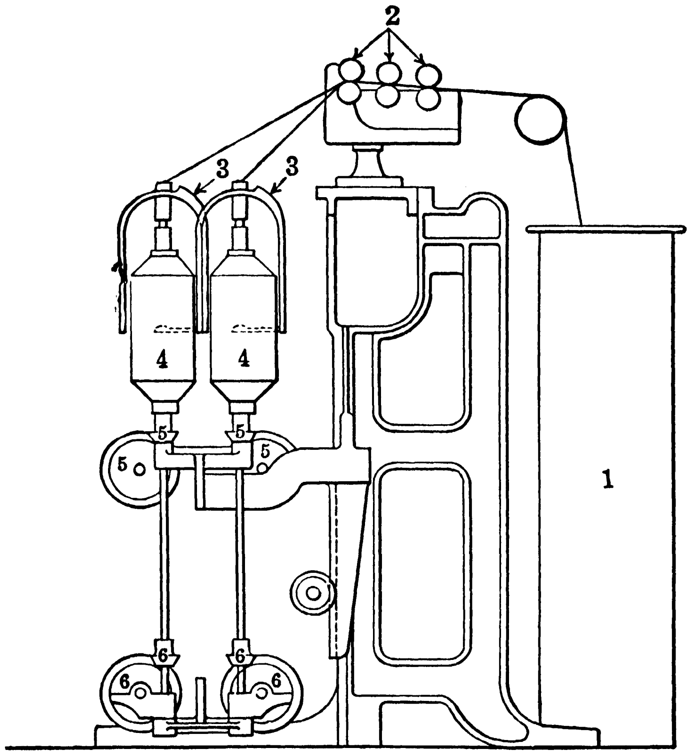


FIG. 116.—Slubbing frame.

passing through several of these frames in the order indicated. Slubbing and intermediate frames are used only in cotton mills; for other fibers only roving frames are used.

All of these frames are flyer frames and very similar in construction.

Figure 116 shows a slubbing frame. The sliver passes from the can (1) through draft rollers (2), through the hollow arm of the flyer (3), and is wound on to the bobbin (4) driven by skew wheels

(5) at a slightly lower speed than the flyer, which is driven by skew wheels (6). The bobbin together with its wheel drive is continuously lifted and lowered during the operation.

The spindle has a footstep bearing and a neck bearing, both usually oiled by hand.

SPINNING

The object of spinning is to draw out and twist the coarse thread received from the preparing department and produce a more or less finely spun yarn. There are four main types of frames, *viz.*, ring, flyer, cap, and mule frames.

Ring Frames.—Figures 117 and 118 show this type of frame and spindle. The thread is drawn by the draft rollers (2) from the

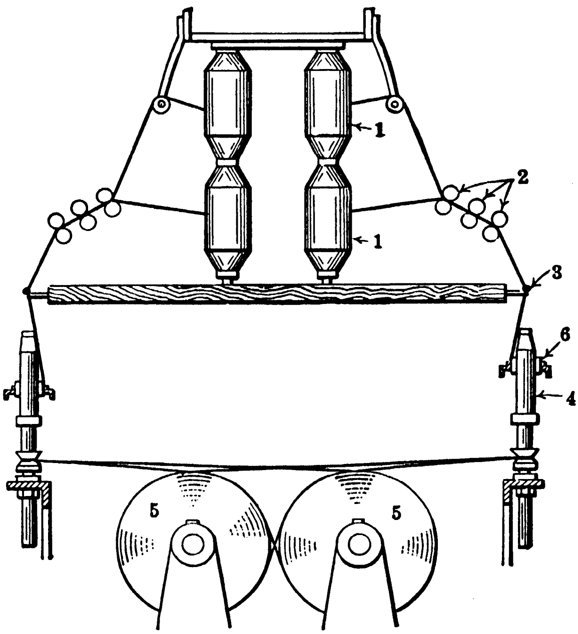


FIG. 117.—Ring frame.

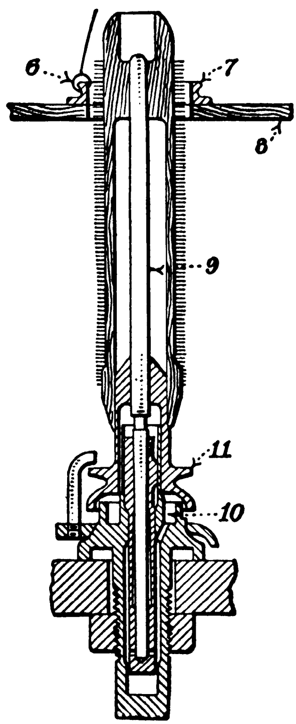


FIG. 118.—Flexible ring spindle.

bobbins (1) and delivered through the eye (3) to the bobbin (4). The bobbin (4) is driven from the tin roller (5), pulls the thread through the "traveler" (6), and continuously winds up the yarn. The traveler revolves on the ring (7) fixed on the lifter (8).

The bobbin is fixed on the spindle (9) which is surrounded by a sleeve and immersed in an oil bath. Several holes are provided in the sleeve which allow the oil to enter freely at the bottom and the side. Some of the oil rises along the spindle, overflows at the top, and returns through a vertical passage to the oil reservoir at the bottom.

The casing and oil reservoir in which the spindle revolves is called the bolster. It will be noticed that the spindle sleeve is provided with a spring which will allow it slight lateral movements in relation to the bolster.

Make-up oil is added at intervals through the oil well (10) which communicates with the bottom oil reservoir and is protected from dust owing to the shape of the driving whorl (11).

The so-called "Rabbeth spindles" are now going out of use; they are similar to Fig. 118 except that the spindle sleeve is

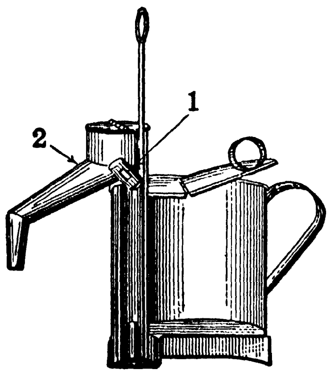


FIG. 119.—Ring-spindle oilcan.

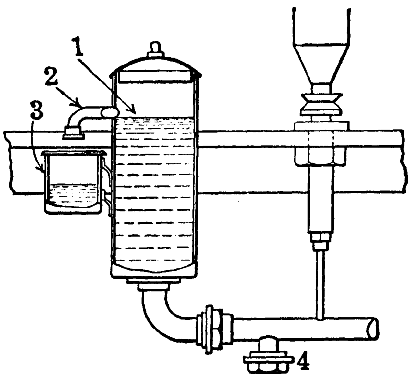


FIG. 120.—Ring-spindle oiling arrangement.

rigidly fixed in the bolster. They cannot be operated at speeds higher than 6,000 r.p.m., as they are then inclined to throw off the bobbins. The flexible-type ring spindles are operated smoothly at speeds ranging from 6,000 to 11,000 r.p.m. notwithstanding slight unevenness in the driving bands.

When a new frame is being started the oil should be pumped out after 2 days' working, and fresh oil introduced. The oil should be renewed after a week's run and again after 4 weeks' further running. Current practice for oiling frames afterward is to add a little fresh oil every 3 months to the oil wells and to empty them for cleaning and recharging once every 12 months.

Figure 119 shows an oilcan for refilling spindle baths. The measure (1) is lowered in the tube shown, filled with oil, and, when

lifted, tips over its contents into the spout (2), which pours the oil into the spindle bolster.

Another type of oilcan is also used for this purpose, in which there is a plunger pump which is pressed down by the thumb. An adjusting screw is fixed below the thumbpiece by means of which the amount of each discharge can be adjusted. The delivery spout may have a sight-feed arrangement to indicate that the pump is in working order.

By connecting all the bolsters to a horizontal oil pipe (Fig. 120) and having an oil-filling vessel (1) at the end, the oil level is correctly maintained for all spindles. It cannot become too high, because of the overflow (2) which discharges excess oil into the small oil receiver (3). The system can be drained by removing the drain plug (4).

While this system is excellent for preventing shortage of oil in the bearings, it carries with it the danger of forgetting to overhaul and clean the spindles, which is important and ought to be done at least once per annum.

Flyer Frames (Used for All Fibers).—Figure 121 illustrates a typical flyer spindle. The flyer (1) revolves and lays the yarn on the bobbin (2), which is lifted and lowered by the lifter (3). The spindle is supported by a neck bearing (4) in the rail (5) and a footstep bearing (6).

The small recess shown in the center is not often found in spindle-footstep bearings but is a great advantage; it prevents heating of the spindle tip and serves to collect dirt which otherwise would cause friction and wear. On very heavy spindles it would probably be beneficial to let the oil circulate, as indicated in Fig. 121, the action being the same as in ring-spindle footsteps.

Flyers used for wet spinning (flax mills) should have their tops enclosed, as shown in Fig. 122, to prevent entrance of moisture, which causes rusting and makes it difficult to unscrew the flyers, unless a heavily compounded oil is used for oiling the spindle tops.

Figure 122 shows a patent flyer spindle (the Bergmann spindle) used for spinning flax, hemp, and jute. The spindle is driven in the usual manner, but the whorl is in line with the footstep, so that the principal object of the neck bearing is to steady the spindle. The neck bearing is made very flexible by means of feather springs (1) and is covered with a lid to keep out dirt and

fluff from the felt oil pad which keeps the spindle well oiled. The whorl protects the footstep from dirt, and in this type of footstep the oil may be arranged to circulate in the same way as in the footsteps of ring spindles. If the spindle is lifted by means of the whorl, the footstep bearing is disclosed for examination and oiling.

The felt-pad arrangement here shown (2) and also used for many cap spindles (Fig. 123) ought to be much more widely

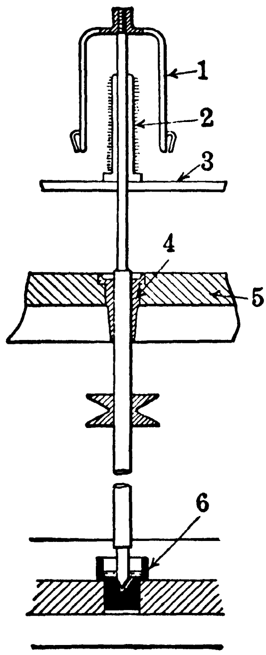


FIG. 121.—Flyer spindle.

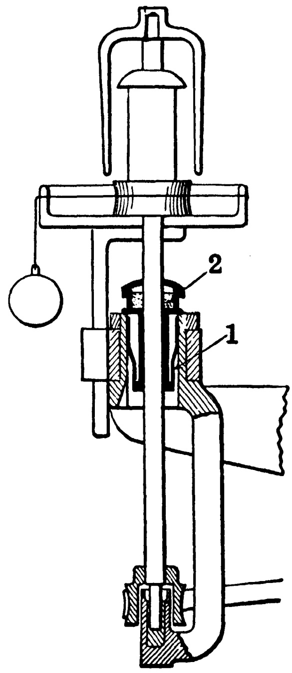


FIG. 122.—Bergmann spindle.

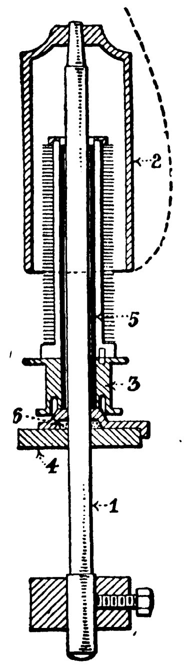


FIG. 123.—Cap spindle with felt-pad oiling.

used for neck bearings of flyer spindles; it is simple, efficient, and economical.

An attempt has been made to introduce oil circulation for the neck bearings. The rail is hollowed out and forms an oil reservoir; the oil passes slowly through tiny openings in the neck collars into the neck bearings; by means of collars on the spindles below the rail, the oil is thrown off into dishes surrounding the spindle, returning through pipes to an oil reservoir, whence a pump takes the oil and delivers it into the rail. The oil thus circulates continuously. It should be drawn off every 3 months and filtered and can be used again, if of good quality. This

arrangement is, however, rather complicated and not so fool-proof as the felt-pad arrangement.

One type of flyer frame, the "Arnold Forster," has the spindles fitted with ball bearings and a self-lubricating felt pad to ensure smooth and easy running.

Cap Frames (Used for Wool, Worsted, and Waste Silk).—A typical cap spindle is illustrated in Fig. 123. The spindle (1) is stationary, and the cap (2) rests on its top. The bobbin is revolved by means of the whorl (3) operated by a driving band from the tin roller. The bobbin continuously winds up the yarn and pulls it over the bottom edge of the cap. The lifter (4) raises and lowers the bobbin, which slides with a long brass tube (5) on the spindle.

Obviously, it is very important to oil this tube well; the felt-pad arrangement (6) is very efficient and economical, it being sufficient to oil the felt pad once every week or fortnight. In many cap spindles there is no felt pad, and the spindle is dabbed once or twice a day with an oily brush; this old-fashioned method means a higher oil consumption, more wear, and about 10 per cent higher power consumption.

Mule Frames (Used for Cotton, Wool, and Waste Silk) (Fig. 124).—The mule spindles (1) are placed on a movable carriage (2) which during the spinning period moves to the left, while the draft rollers (3) draw the thread from the bobbins (4). When the carriage moves to the right, the yarn is wound on the spindles, the fallers (5) moving down into such positions as to guide the yarn correctly on to the spindles.

Mule spindles have a neck bearing and a step bearing, the same as the flyer spindles, the only difference being that they are placed at an angle; the oil is therefore inclined to be thrown out of the footsteps. One method of minimize waste of oil due to this cause is to protect the footsteps, *e.g.*, with Jagger's footstep protector, shown in Fig. 125, which has proved very useful. It also protects the bearing from dirt and fluff, and during oiling it catches all oil; without protectors much oil often runs down the rail and is wasted.

The neck bearings are oiled once, twice, or three times per day according to operating conditions and the class of oil in use. The footsteps are usually oiled the same number of times per week as the neck bearings are oiled per day.

In the center of the mule is situated the headstock, from which all parts of the frame receive their motion, and it is regarded as

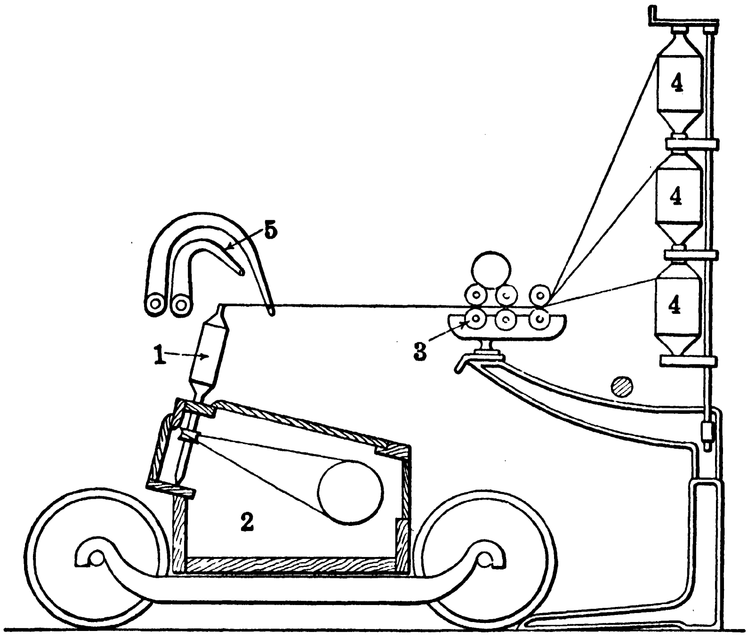


FIG. 124.—Mule frame.

one of the most ingenious and complicated machines in the textile trade.

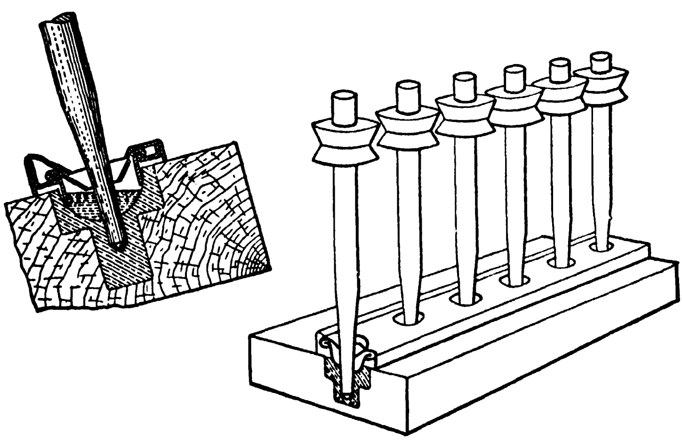


FIG. 125.—Jagger's footstep protector.

Driving bands are usually made of cotton and are affected by the moisture in the air. With most spinning frames the

consumption of power varies approximately 1 per cent for every 6 per cent variation in the relative humidity of the atmosphere in the spinning room. The higher the relative humidity the more the bands contract, and the higher the power consumption.

With some modern frames, notably cap frames and jute spinning frames, the driving bands have their tension maintained uniform by means of weighted tension pulleys, as shown for a cap frame in Fig. 126.

The tension need therefore never be any more than that required for driving the spindles at their correct speeds, and

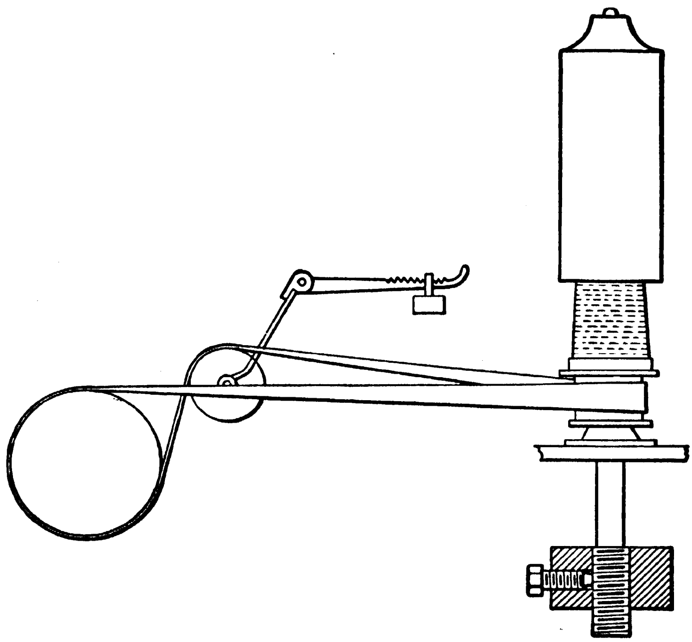


FIG. 126.—Uniform belt tension arrangement.

humidity has no influence on the power consumption. A higher spindle speed can obviously be obtained with this type of drive; and as the spindles are never subjected to excessive strains from the band pulls, their lubrication is easier; lower viscosity spindle oils can be employed with confidence; and the power consumption can then be considerably reduced as compared with frames employing the ordinary type of band drive.

Thread, Twine, and Cord.—In the treatment and manufacture of thread, twine, and cord a variety of light machines are employed, such as doubling, winding, and gassing frames; reeling machines; twisting, twine, and cord machines; thread-polishing

machines; and balling and spooling machines, the lubrication of which presents no striking features.

Doubling frames have either flyer spindles or ring spindles. There are some self-acting doubling frames (twiners) very similar to mule frames. Some winding frames employ ring spindles.

Rope-making machines are either vertical or horizontal, the former being used chiefly for large cables.

From the lubrication point of view these machines, which often look ponderous and complicated, consist essentially of revolving bobbins and are not difficult to lubricate.

Wool Oils and Batching Oils.—*Wool oils* are used for lubricating the fibers preparatory to the carding operation.

With all high-class wool the oil must at a later stage be *completely removed*, as otherwise the yarn will not take the dye properly. Olive oil is undoubtedly the best grade of wool oil. It is easily removed but is expensive, therefore only used for the highest class of material. Other fixed oils, such as nut oil and lard oil, are almost as good as olive oil but are also expensive. Wool oleins (produced from wool grease) and various fatty acids (oleic acids) are much used mixed either with a percentage of other fixed oil or with mineral oil, even up to 80 per cent of the latter. The lower the class of material and the more intense the scouring methods the more mineral oil can be used in the mixture, without running undue risk of having trouble in the dyeing of the yarn. The wool oil must never contain more than 6 per cent of fatty acid, or 12 per cent of wool olein (which normally contains 50 per cent of free fatty acid), as more acid weakens the fibers and destroys the wires on the carding machines as well as the pins of the preparing and combing machines.

Rape oil, cottonseed oil, and the like are not so suitable, as they oxidize and produce gum deposits in the machines.

Some mineral oil—20 to 30 per cent—should always be present in the wool oil wherever permissible, as its presence greatly reduces the well-known tendency that all fixed oils, particularly vegetable oils, have for spontaneous heating, which has been the cause of many outbreaks of fire.

Batching oils are used for softening the fibers of flax, hemp, and jute. Low-viscosity mineral oils are generally used, and occasionally mixtures of whale oil and mineral oils.

WEAVING

Winding, warping, and sizing machines prepare the yarn for the weaving process. The lubrication of these machines calls for no comment.

Looms.—There is an immense variety of looms, from small, quick-speed cotton or silk ones to large, slow-speed carpet looms.

The function of all looms is to form a fabric by interlacing warp and weft threads; there are three essential movements in a loom: shedding, picking, and beating up.

Shedding is the operation of dividing the warp into two portions for insertion of the weft.

Picking is the operation of passing the shuttle containing the weft through the opening formed in the warp.

Beating up is performed by the reed and sley, which, through the action of cranks and connecting rods, advance and recede from the cloth after each "pick" in order to place the weft threads parallel with one another.

Picking motions are called "overpicks" or "underpicks," according to whether the shuttle receives its motion from an arm placed above or below the sley. Overpick is generally used for fast-running looms, and most heavy slow-speed looms have the underpicking motion. This motion is cleaner, as oil is not required about its parts near the cloth, and is therefore preferable for white and light-colored goods, on which oil stains show up more than on dark-colored fabrics.

The shuttle at the end of each journey is arrested by running into an "eye" made of buffalo hide and fixed in the shuttle box; the buffalo hide is steeped in neat's-foot oil to preserve it and to minimize wear of the shuttle nose.

The shuttle gets its motion from a buffalo-hide "picker" sliding on the picker spindle and connected with the driving arm by means of a leather strap. The driving arm has a jerky motion which causes the picker to hit the shuttle hard and send it across the loom to the shuttle box on the other side. It may also be arranged in the form of a lever, which acts on the picker direct.

The picker spindle is lubricated by dabbing it at intervals with an oily brush. A patent automatic picker-spindle lubricator is in use on overpick looms and consists of a small pad saturated with oil and carried by an arm which brings it into contact

with the picker spindle at each forward movement of the sley and, on the return movement, again makes the pad recede, to give room for the passage of the picker.

The danger of oil's getting on to the cloth increases with the speed of the loom. The speed is given in number of picks per minute and ranges from 240 for narrow looms and fine material down to 20 picks per minute for very coarse goods; for most woolen or worsted cloths the picks number from 60 to 70 per minute.

With quick-speed looms the cranks operating the reed and sley are apt to throw oil on to the fabric, particularly so when the bearings are overlubricated.

In velvet looms the fabric is woven over a number of long "needles," which are continuously withdrawn from the finished portion and inserted again; in large velvet looms it is an advantage to oil these needles sparingly with "stainless" oil.

BLEACHING, DYEING, PRINTING, FINISHING

Bleaching and dyeing departments employ comparatively little machinery requiring lubrication. The most important machines from our point of view are probably the hydroextractors.

Printing machines (calico, thin woolen, linen, jute) are usually hand oiled, the same as other printing machines.

The *finishing* processes are very varied.

For *cotton goods* the main operations are singeing, raising, shearing, brushing, steaming, starching, calendering, impregnating, breaking down, damping, mangling, moiréing, embossing, tentering and stretching, doubling, measuring and plaiting, marking, and pressing.

For *woolen and worsted cloth* the main finishing operations are crabbing, scouring, milling, singeing, dyeing, raising, wet rolling, tentering, cutting, brushing, shrinking, pressing.

Again here, *hydroextractors* are used after the dyeing process, and most of the machines used up to this point are fairly heavy slow-speed machines, requiring a viscous oil for lubrication. In the scouring process any oil stains received during manufacture must be scoured out; in the subsequent operations extreme care must therefore be taken to avoid oil stains, and stainless oil should be used for lubrication in the last few stages, *i.e.*, cutting,

brushing, and shrinking. The pressing is generally done in a hydraulic press.

For *linen cloth* the following finishing operations are used: cropping, washing, tentering, beetling, calendering, pressing.

For *jute cloth* the finishing processes are as follows: damping, cropping, calendering, folding.

The only machines calling for comment are the *calenders*, of which there are several forms, all consisting of several heavy rollers called "press bowls" placed horizontally in a strong frame and pressed against one another with more or less pressure either mechanically or hydraulically.

The bearing brasses, top and bottom, should preferably touch the journals over an arc of only 90 to 120 deg., and the edges should be well chamfered to facilitate the entrance of the oil; when there are a number of bearings one above the other, the waste oil from one should be guided into the bearing just below, and so on. Some of the bowls are heated by steam or gas, and their journals become extremely hot—so much so that oil cannot be used, and high-melting-point greases have to be employed. The wear of calender bearings is often very considerable.

OILCANS AND CABINETS

As most oiling in textile mills is hand oiling, it is extremely important to have the oilcans in good condition and see that they are maintained with small spout openings. Some oilers are inclined to cut off the ends of the spouts to make the oil flow more readily, and the result is a great waste of oil, as when a row of spindles is oiled the spaces between them are oiled as well as the

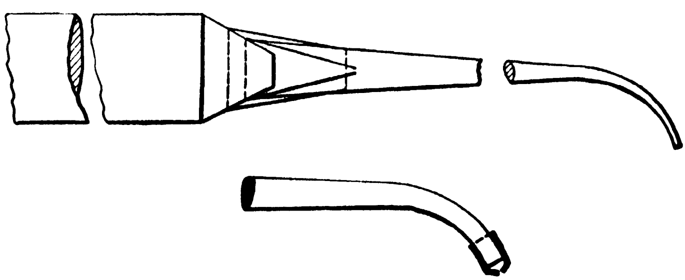


FIG. 127.—Oil-saving devices.

spindles. The oilcans should be so adjusted that as the oiler goes along the frame at a regular speed, a drop of oil falls into each bearing.

Figure 127 illustrates two methods of regulating the oil flow from the oilcan. The top illustration has an inside cone with a tiny opening, so that it is impossible to get a rapid feed of oil from the end of the oilcan spout. The cone cannot be interfered with by the operatives and can be made of any size according to the requirements. The bottom illustration shows the orifice of the spout itself, soldering a strong cap on to the end with an opening of, say, $\frac{1}{32}$ in. The drawback to this arrangement is that the operatives can easily cut off the cap, whereas they cannot interfere with the cone arrangement shown in the other drawing.

It is a great advantage to have in each of the spinning rooms a small cabinet holding a few gallons of oil sufficient, say, for one week's consumption. The cabinets should be arranged with lids that can be padlocked. A small oilcan can be filled from the cabinet without waste, and the oil is always kept clean. Such small cabinets can be used for conveying the oil from the storeroom into the various departments.

STAINLESS OILS

So-called "stainless" oils have several times been referred to. Really stainless oils do not exist; any oil, whether pale or dark in color, whether mineral, vegetable, or animal, will in time produce a visible stain, but the term stainless as applied to textile practice usually means that during the scouring or washing process that most fabrics undergo, oil stains will disappear.

Oil stains take the form of drops, splashes, or streaks. They may be due to oil's dropping from overhead shafting, or oil may have got on to the yarn owing to overoiling the top roller bearings in the spinning frames. Weavers sometimes cover up defects by smearing with dirty oil to escape detection. Oil stains have been caused by greasing the reed, but the most frequent cause is oil throwing from the cranks operating the sley and from the cams actuating the pickers; such splashes show up chiefly on the warp. Stains are also caused by oil splashes from the picker spindle in the shuttle box. Hence the reason why a stainless picker-spindle oil is nearly always used, even if the loom oil employed for other parts of the loom is not stainless.

As to oil dropping from overhead shafting, the oil stains produced are often difficult or impossible to remove, owing to the

presence of fine metallic wearings in the oil, chiefly iron. Iron stains become red; copper or brass stains may become black, gray, or greenish.

Mineral oils give a permanent stain on fabrics, and the darker the oil the more objectionable the stains. Even bloomless oil or oils so pale as to be almost water-white will in time become yellow, owing to oxidation, and the color will continue to deepen with time. The longer the interval between producing the stain and the attempt to remove it (scouring), and the less severe the scouring process, the less oil will be removed. If only a short time has passed, stains may be removed by dabbing with lard oil, olive oil, or other fixed oil, which by blending with the mineral oil makes it stainless; *i.e.*, it can be removed by scouring with soda lye in the ordinary way.

Cotton cloths are bleached, and mineral-oil stains are decomposed in this process, by the successive attacks of alkali and chlorine. For a time after bleaching the oil stains will not appear, but after several months the stains begin to show up yellow.

The best remedy for oil stains is to take precautions that none is formed. In many weaving mills, shafting is grease lubricated for this reason; or, if oil is used for the bearings, they are well fitted up with splash guards and save-alls, which prevent the oil from dripping from bearings or creeping along the shafting and then dropping.

When it is considered necessary to have a stainless oil, the degree of stainless properties required depends upon the length of time the goods are stored before scouring and upon the severity of the scouring operation. Speaking generally, an admixture of 15 per cent of good-quality animal oil or equivalent nondrying fixed oil will impart to the spindle or loom oil sufficient stainless properties for the majority of conditions.

In *cotton mills* many looms require stainless oils only for the picker spindle.

In *woolen and worsted mills* stainless loom oil should be used for lubrication throughout for all looms weaving high-class cloth, *e.g.*, dress cloth or such cloth as is used for naval uniforms.

For low-woolen goods, blankets, etc., stainless oils are never required.

In *linen mills* stainless oils are not infrequently used for high-quality goods, but in *jute mills* stainless oils are rarely if ever

called for, as the material is not of sufficient high quality to justify the extra cost of stainless oils above the cost of ordinary loom oils.

In *hosiery factories*, for material such as woolen underwear and light-colored stockings, stainless oils must be used, as the fabric invariably gets more or less soiled with oil during manufacture. This point is so important that many hosiery factories when testing the oil for stainless properties soak a piece of fabric with the oil, keep it in stock for a certain time, and then scour it to see whether the oil can be entirely removed.

In *lace and curtain factories* pure neat's-foot oil is often used, as the fabrics receive only a gentle washing, and the oil must scour out very easily. Not infrequently the fabrics are not washed at all, and it is then absolutely necessary to have an oil as pale and as stainless as possible.

Neat's-foot oil meets the requirements. It is almost colorless, and even if there are oil stains on the lace or curtains they will be removed the first time that they are washed.

In many *special industries* such as corset manufacturing, the thread used for stitching is oiled occasionally in order to lubricate the needles in the machines. As the corsets are not washed, the oil must be as pale and as stainless as possible. Again here, neat's-foot oil or a mixture of neat's-foot oil with water-white mineral oil is required. If there is a considerable percentage of mineral oil in the mixture, the oil stains will in time become yellow, so that for white goods which are kept in stock a long time this is an important point to keep in mind.

The table on page 325 gives the author's specifications for spindle and loom oils.

As to the *nature of the compound*, rape oil has been used with success, but it is inclined to gum and tarnish, particularly where frames or machinery are exposed to sunlight. With blown rape the tendency to gum is still greater; animal oils have much less tendency to oxidize and should be preferred; sperm oil is excellent but very expensive; lard oil or pale whale oil will give good results; if desired, they may both be used together in the same spindle or loom oil. When stainless properties are required (2S, 3S, and 4S), a small percentage of olein, say not exceeding 3 per cent, is an advantage, as it has good emulsifying properties.

The mineral base of the oil should be pale in color, but it does not matter whether it is an acid-treated or a neutral filtered oil.

Lather oil (see page 329) must possess exceptionally good stainless properties; it must therefore be made from pale-colored, preferably water-white, mineral oil and a large percentage of fixed oil, say 30 to 35 per cent, and its free fatty acid contents must not exceed 5 per cent; more acid will cause trouble with rusting of the needles and other parts. A suitable lather oil may be made from 24 per cent rape, 6 per cent pale whale, 3 per cent olein, and 67 per cent water-white mineral oil of low viscosity, say 75 to 100 sec. Saybolt at 104°F.

GRADES OF SPINDLE AND LOOM OILS

Oil	Viscosity number*	Viscosity, centipoises at 50°C.	Compound, per cent
Spindle oil 1	1	4.5	Nil
Spindle or loom oil 2	3	10	5 to 6
Spindle or loom oil 2S†	3	10	15 to 20
Spindle or loom oil 3	4	13	5 to 6
Spindle or loom oil 3S†	4	13	15 to 20
Spindle or loom oil 4	4	18	5 to 6
Spindle or loom oil 4S†	5	18	15 to 20
Lather oil	2 to 3	8 to 10	30 to 35

* See table, p. 57.
† The letter S indicates stainless properties in the oil.

Each factory has its own formula for lather-oil mixture. The following is typical:

Lather oil	3 gal.
Hard household soap	7 lb.
Water	18 gal.

LUBRICATION OF TEXTILE MILLS

Engine Room.— Steam engines, chiefly of horizontal construction, are used largely for driving textile mills; generally, they drive the various mill floors by rope drives from the flywheel. In modern mills electric driving is not infrequently used, the generators being operated either by steam engines or by turbines, only rarely by gas engines.

As to the lubrication of these engines, the reader is referred to the information given under the respective headings. The author would mention only the desirability of using compounded steam-cylinder oils and using a lower viscosity, preferably filtered cylinder oil in the large low-pressure cylinders.

The practice of using very viscous oil, even cylinder oil, on the guides is not a desirable one; an engine oil like bearing oil 4[1] will generally be found suitable for external lubrication throughout, as well as for the second-motion shaft bearings (rope race). When main bearings or crankpins are difficult to keep cool with this oil, marine-engine oil 1 or 2 (see page 267) may be recommended, even with a gravity-circulation system, which is frequently employed in textile mills.

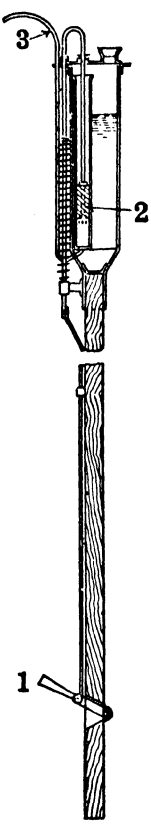


Fig. 128.—Overhead shafting oiler.

Mill Shafting.—The shafting generally operates at rather high speeds—from 160 to 350 r.p.m.—and the bearings are either bottle oiled or ring oiled. The countershafting, gallow pulleys, etc., are often hand oiled. As such hand oiling is a tedious occupation, it being difficult to reach the bearings, a shafting oiler is often used, as illustrated in Fig. 128. By pulling the trigger (1), the piston (2) is depressed against the action of a spring and discharges a small amount of oil through the feeding tube (3).

In many mills the engine oil used in the engine room is also used for the mill shafting, and the waste in power caused hereby is, on the average, 4 per cent of the full mill load. The engine and shafting load (transmission load) is approximately 25 to 30 per cent of the full mill load, and the saving in power by introducing bearing oil 2, see page 135, which the author recommends generally for mill shafting, is roughly 15 per cent of the transmission load. It is a rare thing to find shafting oils in use lower in viscosity than bearing oil 3, and against this oil bearing oil 2 will save about 10 per cent on the transmission load.

[1] See p. 135.

MILL LUBRICATION

Spinning Mills.—Frequently one oil is used throughout, except for ring spindles, which are always given a separate oil, similar in viscosity to spindle oil 2. The mill oils generally used have viscosities ranging from viscosity 5 to 6 (see page 57). The oils are often straight mineral but are sometimes compounded with 5 to 10 per cent of fixed oil.

The author, however, recommends spindle oil 3 for general mill lubrication of preparing and spinning departments as well as for countershafting and gallow pulleys.

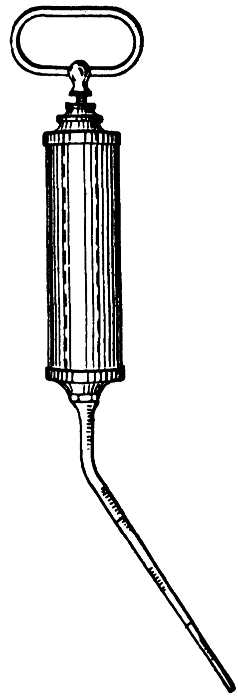


FIG. 129.

For ring spindles, spindle oil 1 is recommended. For high-speed mules, flyers, and all cap spindles, spindle oil 2 is recommended in preference to spindle oil 3, as it gives an even greater reduction in power compared with the oils generally employed.

When the spindle bearings begin to get dry, the spindles "whistle," vibrate ("dance"), and frequent breakages of the yarn occur. With compounded oils the tendency to run dry will always be found to be much reduced, as compared with straight mineral oils.

Compounded oil must not be used for ring spindles, as in time it will produce a gummy deposit which will interfere with lubrication, choking the vertical passage in the bearing. If the oil is of too low viscosity or badly refined, it will cause continuous wear on the step bearing, so that notwithstanding repeated cleaning the oil will always become discolored.

The pump illustrated in Fig. 129 is used for the purpose of extracting old oil from bath-spindle bearings before they are cleaned and reoiled. The pipe is inserted in the spindle bearing; the piston is operated up and down by the handle, drawing the dirty oil out from the bearings and discharging it into the main barrel of the pump, which can afterward be emptied.

In wet-flax spinning, a special oil, say spindle oil 4S, must be used for oiling the flyer spindle tops, when they are of the open

type. Many mills use lard oil or olive oil, but these oils are unnecessarily expensive and no better than the oil just mentioned. The advantage of compounded over straight mineral spindle oils is that lower viscosity oils can be used and yet they will be found to be more "oily" than the more viscous straight mineral oils; therefore they reduce friction and last longer. They seem to form a very tenacious oil film in the spindle bearings and are displaced only with difficulty. This is no doubt due to the presence of the fixed oil which we know excels mineral oil in the property of oiliness.

The best practice is to oil the neck bearings of flyer spindles and mule spindles while the frames are running. This is Continental practice and means that thinner oils can be used efficiently, as one is always certain of the necks' being thoroughly oiled. Oiling when the spindles are standing, as is the practice in England, may mean that in some necks, particularly when they are worn, the oil runs straight through the clearance between neck and collar. When neck bearings are fitted with felt pads for lubrication, it is immaterial whether they are oiled while the spindles are running or when standing.

As to typical savings in power accomplished on spinning frames, see pages 330 to 334. In most mills the oils recommended above will save over 8 per cent of the departmental loads, equivalent to 6 per cent of the full mill load.

Top Rollers.—In some cotton mills spindle oil 3 is often sufficiently viscous for the top rollers; but in others, as well as in most other spinning mills—woolen and worsted mills in particular—a more viscous oil is required; and, speaking generally, the engine oil used in the powerhouse will prove very suitable as a top-roller oil. In flax mills a special preparing-room oil is often used for the preparing room and for the press rollers in particular. This is found necessary when the roller covers are not fitted with flannels; but if they are so fitted, an oil like bearing oil 3 can be used satisfactorily. Tallow or white tallow greases are often used for top rollers, especially when they are badly worn and therefore difficult to lubricate; bad lubrication of the top rollers causes a jerky motion and unevenness in the yarn.

Traveler.—The ring upon which the traveler moves in a ring spinning frame should be sparingly greased with clean tallow.

Combers.—For combers a viscous oil like the engine oil used in the engine room must be used for lubrication of the slow-moving parts, whereas the spindle oil should preferably be used for the dabbing motions. When the circles are highly steam heated, a noncarbonizing very viscous mineral oil is required, having a high viscosity—about No. 11 (see page 57)—and made from a pale nonparaffinic-base distilled oil mixed with good-quality filtered cylinder stock.

Weaving Mills.—Loom oils should preferably be compounded for the same reason as given for spindle oils.

The percentage of compound need not be more than 6 unless particular stainless properties are required. For high-speed light looms, loom oil 2 or 3 is recommended; and for slow-speed heavy looms, loom oil 4. The oils must, of course, be sold as loom oils; if branded spindle oils, they would almost certainly be condemned by the mill people. As stainless loom oils or as stainless picker spindle oils (particularly when overpick motion is employed), loom oils 2S, 3S, and 4S are recommended.

Bleaching, Dyeing, Printing, and Finishing.—Bearing oils 3 and 4 are generally used. The calenders, however, require a very viscous oil, such as bearing oil 5 or oil even more viscous.

High-melting-point greases, with melting points suitable for the temperature of the bearing journals, are also used.

HOSIERY MACHINES, POWER SEWING MACHINES, ETC.

Hosiery machines are chiefly knitting machines and either *straight-bar machines,* knitting flat pieces of material; or *circular machines,* knitting tubular pieces. Bar machines have several hundreds, and the largest circular machines many thousands of needles. The needles require some slight lubrication so that the yarn may pass easily through them. The lubrication is done by the yarn, which before entering the machines is passed through a trough containing emulsified-lather oil; as the yarn leaves the trough, surplus lather is squeezed out by rollers.

For general lubrication of most circular machines and power sewing machines, loom oil 2S will be found suitable. Bar machines require a somewhat heavier oil, such as loom oil 3S, and this oil may also be recommended for circular machines that have become worn.

Stainless properties are practically always required, and the oil ought to be thoroughly tested in this respect, as mentioned on page 323.

POWER REDUCTION IN TEXTILE MILLS

Very great reductions in power can be accomplished by paying careful attention to the selection of suitable oils for each department in the mill, as well as for the mill shafting and the powerhouse.

In a ring-spindle frame, for example, about 80 per cent of the power is required for driving the frame empty, only 20 per cent being consumed in handling the yarn. In the case of preparing machinery, an even greater percentage of the full-load power is required to run the machines or frames empty.

In a jute-spinning frame of the ordinary type the power consumed usefully is very much the same as in a ring-spindle frame, but in the modern spinning frames, in which the tension of the driving bands is kept uniform, there is a great reduction in the power consumed by the frame, and only 65 per cent of the full-load power is required for running empty.

In mules or looms a great portion of the power is used in overcoming the inertia of the moving parts which have to be accelerated, stopped, and, in the case of the loom, quickly changed. In the loom, for example, the sley moves backward and forward quickly; the picker motion just as quickly; and the shuttle is thrown quickly to and fro, all of which requires a great deal of power, so that the percentage of power influenced by lubrication in a mule or loom is less than in ring-spinning frames.

In the average steam-engine-driven textile spinning mill, 1½ to 2 lb. of coal is consumed per indicated horsepower per hour; and the heat value actually converted into useful work in the form of preparing or spinning the yarn, etc., will not be more than 1½ to 2 per cent of the heat value of the coal used under the boilers.

The possible saving in power by introducing correct grades of spindle and loom oils is nearly always considerable. To take an example: On a ring-spinning frame using an oil like spindle oil 3, another oil like spindle oil 1 was introduced. The results were as in the table on page 331.

The saving in power in this case amounted to 8.8 per cent and indicates the results that can be obtained in most textile mills, as the first oil used is typical of the ring-spindle oils now in general use and is quite unnecessarily viscous, except perhaps for frames with old and worn Rabbeth spindles. Whenever a change from a viscous to a less viscous oil is carried out, the low-viscosity oil will turn black, the discoloration being due to extremely fine metallic particles from the rubbing surface. In other words, very slight wear takes place, the surfaces adapting themselves to the new oil. After the pumping-out and recharging process, the fresh oil should work perfectly clean.

Such a saving in power is worth many times the value of the oil itself, and, in addition, the yarn produced by the frame will be found more uniform, because of the smoother running of the spindles.

PARTICULARS OF RING FRAME

Number of spindles	300
Diameter of line-shaft pulley	40 in.
Diameter of frame pulley	15 in.
Diameter of tin roller	10 in.
Diameter of whorl	1 in.

	Viscous oil	Low-viscosity oil
1. Influencing conditions:		
Counts spun	10½	10½
Weight of yard per doff, pounds	14.0	14.6
Room temperature, degrees Fahrenheit	89	90
Relative humidity, per cent	62	62
2. Power (measured by Emersons dynamometer):		
Brake horsepower	3.64	3.32
3. Temperatures, degrees Fahrenheit:		
Temperature of spindle rail	98	97
Frictional heat	9	7
4. Loss due to belt and band slip:		
Speed of line shaft, r.p.m	281	281
Theoretical speed of tin roller	749	749
Registered speed of tin roller	740	745
Belt slip, per cent	1.2	0.7
Theoretical speed of spindles	7,400	7,450
Registered speed of spindles	7,010	7,085
Driving-band slip, per cent	5.3	4.9

Improved lubrication means lower frictional heat, which is evidenced by a lower rise in temperature of the spindle rail above the room temperature.

The driving bands which run over the tin roller and drive the spindle always slip slightly; when they are in proper condition the slip should not be more than a few per cent. The lower friction of the spindles will reduce the band slip and thus slightly increase the spindle speed, as shown by the test. Less band slip also means less wear of the driving bands, and the annual consumption of driving bands is quite a good indication of the quality of ring-spindle oil used. The reduced power consumption of the frame will tend to decrease the belt slip in the driving belt, and this effect is also shown in the test figures.

In a worsted spinning mill a test was carried out on a spinning frame having 216 open-type flyer spindles. The oils in use on the two tests were oils *A* and *B*. Oil *A* was a straight mineral oil having a viscosity of 5 centipoises at 50°C. Oil *B* is spindle oil 2, specified on page 325. The power measurements were recorded by an Emerson dynamometer, and, besides particulars of the horsepower, readings were obtained of the rail temperature, room temperature, relative humidity, tin-roller speeds, and spindle speeds

Oil in use	Horsepower required to drive frame	Rise in temperature of spindle rail
A	2.39	10.3
B	2.15	5.4

Reduction in horsepower required to drive frame. . .0.24, or 10.0 per cent
Reduction in temperature of spindle frame. . . . .4.9°F., or 47.6 per cent

Oil in use	Tin-roller speeds per minute			Spindle speeds per minute		
	Calculated	Actual	Slip, per cent	Calculated	Actual	Slip, per cent
A	231	225.3	2.47	2,054	1,893	7.8
B	231	225.4	2.42	2,054	1,900	7.5

every 10 min. for 2 hr. in the forenoon and 2 hr. in the afternoon. Before testing, the frame was cleaned and well oiled with oil *A*; and after the first test was completed the footsteps were again wiped out, and oil *B* was put into use. The frame was then allowed to run for a full day before the second test took place.

The temperature of the atmosphere and the relative humidity were the same on both tests.

In one mill the introduction of spindle oil 2 for cap spindles reduced the wear of the driving bands very considerably. It was brought to the overseer's notice that the band boy had very little work to do; when the boy was asked why he did not attend to the bands, he replied that as soon as the new oil was put into use they seldom broke, and he had none to repair.

In another case the power consumption of the frames with oil *A* was so great that the belts were always slipping on the pulleys. It was not possible to get all the spinning frames running until seven A.M., as it took considerable time before the oil became warm and fluid enough to reduce the power consumption of the frames. The steam engine driving the mill was hardly powerful enough to cope with the load.

Comparative power tests in textile mills should therefore never be carried out on Mondays when the mills have been shut down for the week end. The oil cools down in the bearings, and the starting load on the Monday morning is always considerably higher than later on during the week.

When engines are overloaded, it is often difficult to start the mill on full load—on Monday mornings in particular—and it may even be necessary to leave out one or two departments until the engine eventually is able to cope with the load. The introduction of more suitable grades of oil reduces the horsepower required and particularly the starting horsepower in the early part of the week, so that the engines are able to get up their normal speed much more rapidly and maintain their speed more uniformly during the day. There have been many cases of overloaded engines which after a change in lubrication have been found quite powerful enough to drive the mills, so that a study of the lubricating conditions has saved such mills the heavy expense of putting in a new engine or introducing electric motors to take care of part of the load. When better lubricants are introduced, the improved working of the machines is soon observed by the easier

starting of the machines or by their running for a longer time after the driving belt has been moved on to the loose pulley.

Quite a simple test for the engine and shafting load is to run the engine and shafting at the lunch hour when all the machinery in the mill is stopped; then shut off steam and observe the number of revolutions made by the engine before it comes to a standstill and the time taken. An improvement in lubrication is immediately shown by the greater number of revolutions and the longer time that passes before the engine comes to rest.

When an appreciable reduction in power has been accomplished in a textile mill by introduction of better lubricants, the main effects are the following:

1. A reduction in the total horsepower of the mill as well as in the engine and shafting load and the power consumed by each department in the mill.

2. A reduction in the amount of coal required for power purposes. When the reduction in power is appreciable it should always be possible to find a corresponding reduction in the coal consumption, particularly when the amount of coal used for heating and power are kept separate.

3. A reduction in the temperature of all bearings and spindle bases.

4. An increase in the speed of countershafting, machines, and spindles due to reduced slipping of driving belts and driving bands. If the engine has been overloaded, the reduction in power will bring about an increase in the engine speed, and the engine will reach its normal speed more quickly after starting.

5. A slight increase in production, due chiefly to fewer stoppages, as many stoppages are caused through defective lubrication.

6. A decrease in the wear and tear of the machines as well as of belts and driving bands. The decrease in the wear of the driving bands may often be quite considerable.

CHAPTER XXIV

MINE-CAR LUBRICATION

The tubs in collieries are known by many names, such as trams, hutches (Scotland), and mine cars (United States). The following remarks apply chiefly to mine cars in collieries.

Their lubrication consumes on an average 50 per cent of the oil used in a colliery and is of great importance, as trouble with the tub lubrication may easily cause reduced output. The tubs are preferably made of steel; with wooden tubs dust shakes through the floors, contaminates the axles, and interferes with lubrication. Their carrying capacity is from 4 cwt. to 2 tons. Tubs have two axles usually of rolled steel ranging in diameter

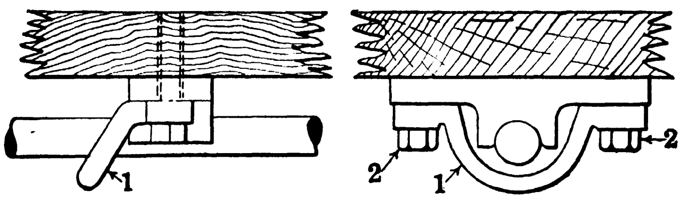


Fig. 130.—Open-type bearing.

from $1\frac{1}{4}$ to 2 in., wheels ranging from 7 to 16 in. in diameter, and bearings of a length preferably not less than twice the diameter of the axle.

Wheels and Axles.—With *fast wheels* the wheels are riveted to the axle, which revolves in the cod bearings.

With *loose wheels* both wheels are loose on the axle, which does not revolve.

With *loose wheels and axles* the wheels as well as the axles are free to rotate. Where the track has many curves this system or a combination of one fast and one loose wheel is often used.

Cod Bearings.—These may be either outside or inside bearings and either open or enclosed. Figure 130 shows a typical open-type bearing. The spectacle plate (1) should be bent well to one side, so that it does not foul the automatic oilers when the tub passes over them. The bolts (2) should preferably be put in from the bottom and must not project below the axle, as in Fig.

131, when they will foul the oilers. Figure 132 also shows an undesirable condition from the oiling point of view, and it may be produced by excessive wear of the bearing shown in Fig. 130.

Cod bearings may be of cast iron but are usually of cast steel, and where there is no dust or the dust is not of a gritty nature they

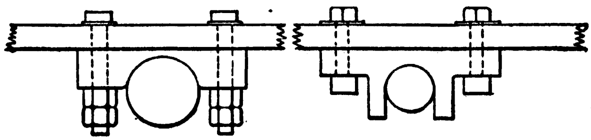


FIG. 131. FIG. 132.
Cod bearings.

are preferably lined with white metal. The question of grit is of importance only when the speed of the tubs is sufficiently great to raise the dust to any extent.

When, as is sometimes the case, the bearing entirely encloses the axle, or the spectacle plate is in the center, the axles cannot be

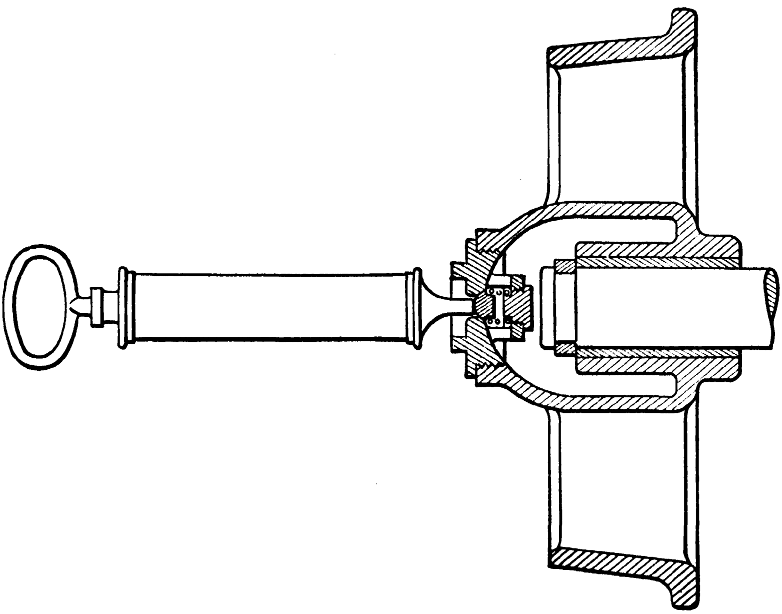


FIG. 133.—Rowbotham wheel.

oiled automatically, except by squirt oilers, *e.g.*, the Abbott oiler, which will be referred to later. Figure 133 illustrates the Rowbotham wheel, much used in South Wales on account of the fine dust existing in the mines. The wheel is loose on the axle, and the hub serves as an oil reservoir; the oil is injected by a syringe against a self-closing ball valve, as shown. Enclosed wheels

of similar types are much used in the United States, frequently employing oil-soaked waste; and on the Continent there are several types of roller or plain bearings so arranged that the bearing housings at either end of the axle are combined and form a sleeve surrounding the axle, as shown in Fig. 134. The space between the axle and the sleeve is filled with oil through a filling hole in the center. The lubrication is very economical; one filling may last a month or more. The oil works its way out through the ends and keeps the bearings clean. The latter should have good felt packings when using oil, as otherwise it works out too freely and is wasted. With roller bearings a very soft grease is better than oil and more economical.

OILERS AND GREASERS

Hand Oiling.—In some mines the tubs are still oiled by hand, although this practice is fast disappearing. The tubs are turned

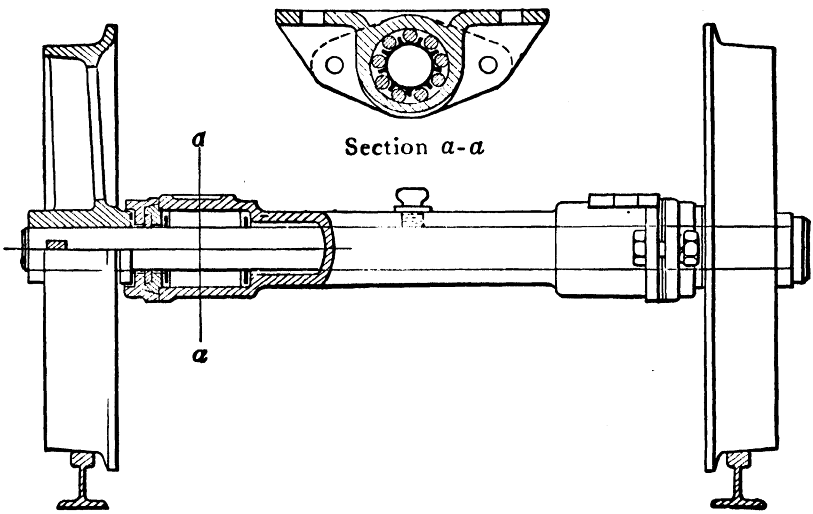


FIG. 134.—Roller bearings for mine cars.

over first on one side, then on the other; the oil is applied through "coffeepots;" loose wheels are given a "spin" when being oiled to get the oil well worked into the bearing. By flattening the end of the oilcan spout it is possible to reduce the waste of oil to some extent. It is good practice to use thick oil and heat it in a steam-heated tank; cold oil will not run through a flattened spout; and if an ordinary wide spout is used, most of the oil will be wasted.

With fast wheels, the axles may be oiled by hand by means of a brush; to avoid undue waste, the brush should not be dipped in the oil but into cotton or wool waste kept well soaked with it.

Hand greasing may be done by a stick or a brush but is always very wasteful; the surplus grease drops on to the track and makes it greasy and dirty.

Mechanical Oilers.—Figure 135 shows an early type of greaser—a scalloped wheel connected to the axle by a spiral spring, which allows the wheel to be depressed when the axle passes over it and gets smeared with grease. Coal dust gets into the trough and gives trouble. When the grease is thick or becomes thick, owing to cold, the wheel cuts a track in it and revolves without

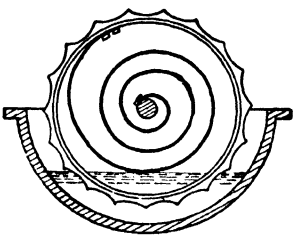


FIG. 135.—Scalloped-wheel greaser.

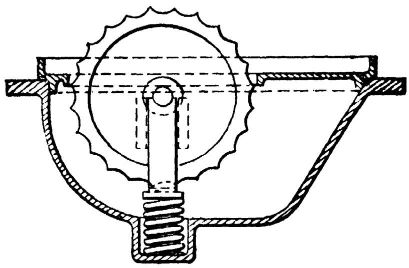


FIG. 136.—"Knockout" greaser.

lifting the grease. Revolving brushes have been used instead of the wheel but are very wasteful indeed.

The "knockout" greaser (Fig. 136) is a better form of greaser; it is simple and accessible; the wheel can be lifted right out. This greaser is also used for oil but should then have a brake fitted so that it soon stops after the axles have passed; otherwise it causes waste by throwing the oil.

The disadvantage of this and similar greasers when using oil is that the oil drains off during an interval, so that when the next set of tubs comes over, the first few tubs do not get properly oiled. All tub oilers should be so designed that none of the axles can pass over without being oiled. Most types have some form of pump actuated by the tub axles; the wheels of the tubs passing over an oiler should therefore be of the same size and as uniform as possible. When the wheels are much worn, the axles of those particular tubs are nearer the ground, depress the pump plunger too much, and cause waste of oil.

The oiler or its foundation should be secured firmly to the rails; otherwise, it may be pushed into the ground with the result that the axles no longer depress the plungers sufficiently.

Figure 137 illustrates an oiler designed by W. A. E. Woodman and the author. It is suitable only for open-type bearings (Fig. 130) and fast wheels. It has a large container; the lid carries the pump barrel with its suction valve. The bow is guided by two vertical guide bars and carries the pump plunger with a

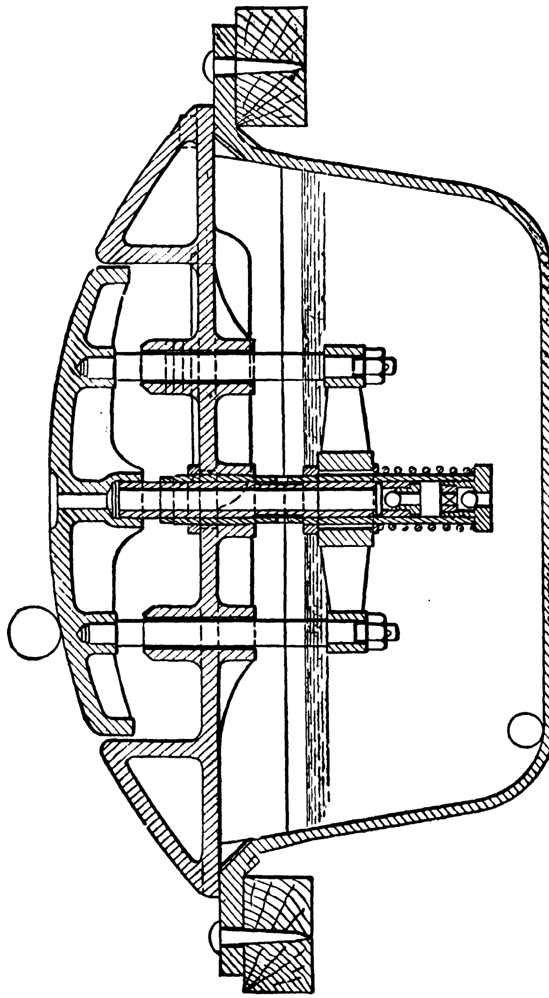


FIG. 137.—Automatic pump oiler. (*Woodman and Thomsen.*)

delivery valve at the bottom. The guide bars are connected by a crosspiece, which is forced upward by a spring against a stop; the stop is adjusted vertically by a single outside adjustment, thus determining the depression of the plunger when the axles pass over the bow, and wipes the oil from the oil delivery well in the center of the bow. The lid entirely covers the container and is provided with a large filling hole; the edges of the hole are

raised above the level of the lid, to prevent dust and dirt from getting in when the container is being filled. This is a very important point, and for the same reason the filling lid is so designed that it cannot be left open but automatically falls and closes the opening.

In many types of oilers for open-type bearings, the haulage ropes and coupling chains are liable to get underneath the bow and bodily pull the oiler out of the track. This has been provided against by placing at either end of the bow a fin, which is cast on to the lid and gives an inclined plane for the rope or chain to run up and slide clear over the bow. These fins also act as buffers against severe end shocks.

The oiler has to be well made, but in the author's experience tub oilers cannot be made too well. The oiler shown has worked under very severe conditions in South Wales (very heavy tubs) where no other oiler has been able to stand up to the conditions. After many months' working, no perceptible wear had taken place, no dirt had got into the container (only a coarse sieve is provided), and the adjustments had never been touched. Equally good results have been obtained in Lancashire and other collieries, where the conditions are much less severe.

The oilers are usually placed on the same foundation, but sometimes it is best to stagger them. This gives more room for the ponies (where ponies are used) and is also advantageous where the spectacle plates are inclined to foul the oilers. The rail at the first of a pair of oilers and a little before is raised, say, 1½ in. above the other rail. This makes the tub body slide over toward the lower rail and gives more clearance to oil the underside of the axle in the cod bearing. The same performance is reversed at the next oiler which is placed, say, 10 to 15 yd. farther along the track.

On the surface the oilers should not be exposed to rain but placed under a roof or shelter. Down pit the oilers should be laid down in a dry place and not where surface or roof water is likely to come in contact with them. On entering a wet district, the tubs should be oiled so that the oil film will last until they reach the next oiler, which should be placed immediately after the wet district. It is much easier to renew and maintain the oil film if it is never allowed to be completely washed away; the oil does not adhere well to a wet axle.

Figure 138 shows one form of the Abbott oiler oiling outside axle bearings of the type shown in Fig. 132, which can obviously not be oiled by the oiler shown in Fig. 137. The plungers (1) are depressed quickly and so timed that they squirt oil on to the underside of the axles; surplus oil is caught by the save-all (2).

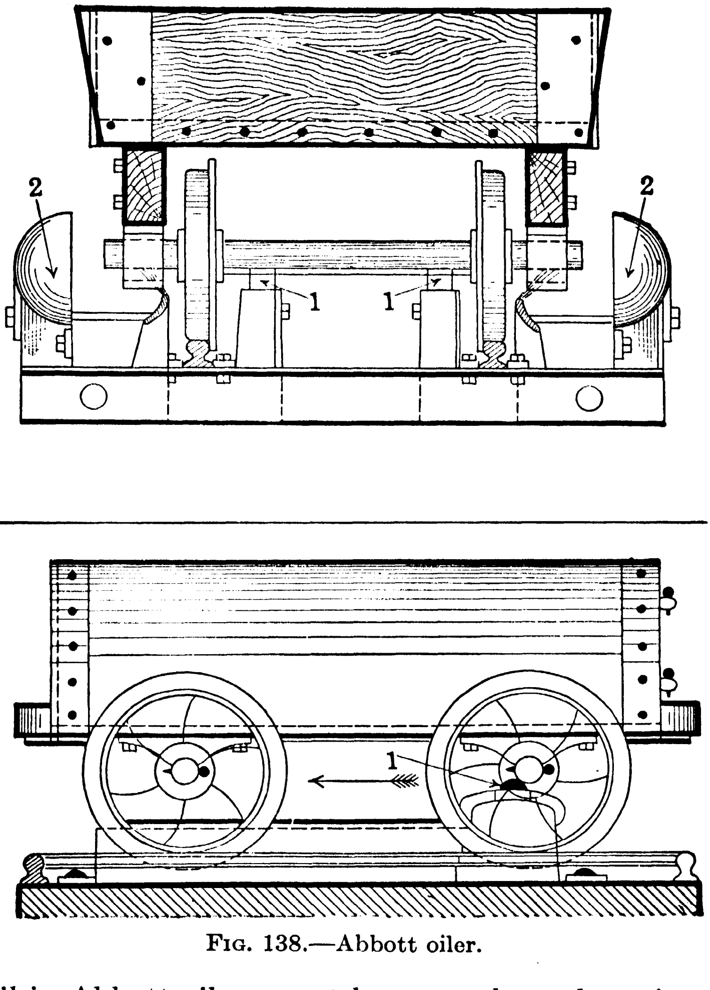


Fig. 138.—Abbott oiler.

The oil in Abbott oilers must be steam heated to give a good and uniform squirt; for this reason they cannot be used down pit, where there is no steam.

Distance between Oilings.—Apart from wet districts, it may be said that the larger the wheels and the cooler the pit the longer the distances that can be allowed between the oilers, other things being equal. The axles should never be allowed to run dry; it is better to space the oilers closer together and give them less oil per

oiler than to space them so far apart that there is a risk of under-lubricating the axles. Efficient oiling saves wear and tear and means less power required for hauling the tubs. It is good practice not to exceed $1\frac{1}{2}$ miles between oilings, and with small wheels and narrow bearings oiling every mile will be required.

In some mines using a very viscous oil, tubs have run as much as 4 miles on one oiling, but the lubrication has not been all that could be desired.

Before grades of tub oils and greases are described, it is necessary to refer to the various systems of haulage.

SYSTEMS OF HAULAGE

With *endless-rope haulage* the empty tubs are continuously and slowly hauled into the mine and return loaded, the speed of haulage being from 2 to 4 m.p.h.

With *main haulage* the shaft is inclined toward the workings, the incline exceeding 1:24. The empty tubs run into the shaft by gravity and are hauled out loaded; only one rope and one haulage drum are employed.

With *main and tail haulage* two ropes are used; the main rope hauls the loaded tubs out, and the tail rope pulls the empty ones in. The haulage drums are both operated by the same engine. The speed for main and tail haulage may be as high as 20 m.p.h.

The haulage ropes are driven either by a steam haulage engine or by an electric haulage engine. In the United States ropes are discarded in many mines, and the mine cars pulled out or in by electric or compressed-air locomotives.

LUBRICANTS

Grease can be used only for slow-speed conditions; if used on main and tail haulage, it gives a great deal of trouble and wastes much power in hauling the tubs; also, the wear is excessive. Good tub oil as compared with grease gives cleaner and better lubrication, and not only does it save a great deal of power, but rightly applied it also saves in cost. In most cases where a change has been made from grease to oil, the saving in consumption is 50 per cent or over. With electrically operated haulage the difference between grease and oil or even different qualities of oil is readily observed.

With ball or roller bearings there is very little difference in friction between oil and grease. Very little lubricant is required,

but it must be of good quality (see under Ball and "Roller Bearings").

The lubricant must be selected according to the temperature of the mine, whether it is dry or wet, the amount and nature of the dust, the type of oiler employed, and the distances between oilings.

Temperature.—In deep, badly ventilated pits the temperature is higher than in shallow well-ventilated pits. The higher the temperature the more viscous the oils required. In cold pits a good cold test will be required, so that the oil will not be too sluggish in the automatic oilers.

Wet Pits.—In very wet pits good-quality grease may have to be used, if the tubs must run long distances between oilings. It is not so easily washed off the axles as is oil. Tub oils for wet pits should have a tendency to emulsify with water.

Dust.—*Fire-clay dust* and *coal dust* have a drying effect on the oil film. Free-flowing oils and frequent oilings are desirable with these dusts.

Stone or *flint dust* will cause heavy wear; the wear can be minimized only by using viscous oils of good quality and by frequent oilings. If a sticky oil is used, the dust forms a grinding paste with the oil and causes heavy friction and wear.

Type of Oiler.—*Wheel greasers* (Figs. 135 and 136) can use oil of almost any description and also grease, as long as it is not too thick.

Abbott oilers can use oils with a poor cold test, as they are usually steam heated. Such oils solidify on the cold axles and form a film with good lasting properties if the oil is of good quality.

Pump oilers (Figs. 137 and 138) when not steam heated cannot use oils that are so sluggish at the working temperature that the pump fails to act.

Hand Oiling.—When the oil is heated, it need not have a good cold test, but this may be necessary when it is not heated.

Distance between Oilings.—With long distances between oiling more viscous oils are required than when the oilers are closer together.

GRADES OF OILS AND GREASES

It is customary to use black oils—one for summer use with a cold test of 25 to 30°F., and a winter oil with a cold test of 5 to

15°F. These oils are dark residual oils from distilling lubricating crudes or from redistillation of lubricating-oil distillates, or they are mixtures of such oils with low-viscosity, low cold-test oils, so as to produce oils of the right viscosity and cold test.

The asphalt contents should preferably not exceed 3 per cent in the better quality oils; but for rough service, oils with much higher asphalt contents have been used. Typical viscosity figures for black oils are given in the table below.

Black oil	Viscosity number[1]	Viscosity, centipoises at 50°C.	Cold test, degrees Fahrenheit
Winter	9	56	$^{5}/_{15}$
Summer	10	76	$^{25}/_{30}$
Heavy	12	125	$^{50}/_{60}$

[1] See table, p. 57.

Black tub greases are usually rosin greases. Sometimes so-called "floating greases," containing talc, are used.

There are various formulas, and the better qualities contain no filler. A rough test for the presence of filling material is to burn a sample and examine the residue (lime, talc, etc.).

CHAPTER XXV

STEAM ENGINES

LUBRICATION OF CYLINDERS AND VALVES

Stationary and Marine Engines.
With special sections on:

Corliss Value Engines.
Colliery Winding Engines.
Uniflow Engines (Stumpf Engines).
Marine Engines.

Locomotives.

STATIONARY AND MARINE

Steam engines are the most reliable and most highly developed and specialized of all power producers.

Most land steam engines are horizontal, and practically all marine engines are vertical, except a few "inclined" engines employed in paddle steamers.

They can be classified according to:

Arrangement and number of cylinders.
Type of valves employed.

Arrangement and Number of Cylinders.—Steam engines may have one, two, or three cylinders side by side, all using *high-pressure steam.*

Two-cylinder engines—twin engines, mostly horizontal—are used as colliery winding and haulage engines or steelworks rolling-mill engines.

Three-cylinder engines—triple engines, mostly horizontal—are used as steelworks rolling-mill engines.

Engines in which the steam expands in two, three, or four consecutive stages are called compound, triple-expansion, and quadruple-expansion engines, respectively. Some triple-expansion engines have two low-pressure cylinders and are therefore four-cylinder, triple-expansion engines.

There is a tendency to turn away from triple-expansion engines in favor of compound engines of various types, such as four-cylinder compound engines with two high- and two low-pressure cylinders or three-cylinder compound engines with two high- and one low-pressure cylinders or one high- and two low-pressure cylinders.

The two cylinders of a compound steam engine may be arranged one behind the other—a tandem engine—or side by side—a cross-compound engine—or with horizontal, high-pressure and vertical, low-pressure cylinders—an angle-compound engine.

Types of Valves.—Many types of valves are in use, but they may be divided into four main groups, as follows:

1. Slide valves.
2. Corliss valves.
3. Piston valves.
4. Drop valves, or poppet valves.

Slide valves are not used in single-cylinder engines of over 125 hp., because they are inefficient.

In compound and triple-expansion engines, slide valves may be used for the intermediate- and low-pressure cylinders in sizes from 50 to 750 hp. per cylinder.

Slide valves can be used only for *low superheat,* as their unsymmetrical shape causes warping. They can, however, be used at *high speed,* as they are positively operated.

Corliss valves are used rarely in engines below 125 hp. in size, as they are not so adaptable to the high speeds at which small engines operate. They can be employed with *moderate* superheat.

Piston valves, notwithstanding their rather low efficiency, are used even for very large power units, as they can be operated at high speed, with high steam pressure and high steam temperature, and are very reliable for severe service, as in colliery winding engines and steelworks rolling-mill engines. They are used largely in marine engines and for locomotives.

Drop valves, or poppet valves, are used for the highest powers, on account of their great efficiency; they are not used for power units below 125 hp., for the same reason that Corliss valves are not employed. Drop valves can be operated with high steam pressure and high steam temperature at higher speeds than the Corliss valve but not at such high speeds as the piston valve.

Land Engines.—Below is shown, for the different types of valves, the normal range of steam pressure, maximum steam

Valve	Steam pressure	Maximum steam temperature, degrees Fahrenheit	R.p.m.	Horsepower per cylinder	Number of cylinders	
					Horizontal	Vertical
Slide.....	60 to 135	450	350 to 60	Up to 125	1	1
Corliss...	80 to 160	525	150 to 60	125 to 2,000	1, 2, or 4	1, 2, or 3
Piston....	90 to 1,800	850	500 to 90	Up to 3,000	1, 2, or 3	1, 2, or 3
Drop or poppet.	120 to 450	750	180 to 90	125 to 3,000	1 or 2	

temperature permissible, revolutions per minute, horsepower per cylinder, and number of cylinders employed in horizontal as well as vertical land engines.

The table on page 348 shows the most frequent combinations of valves employed in single-cylinder, twin, triple, compound, and triple-expansion engines as used for land purposes.

Marine Engines.—Small marine engines are compound, say below 100 hp. for single units. The vast majority are, however, triple expansion. Single units above 3,000 i.hp. are frequently triple-expansion four-crank engines, with one high-, one intermediate-, and two low-pressure cylinders.

Single units above 4,000 i.hp. are frequently quadruple-expansion engines, with one high-pressure, one first-intermediate, one second-intermediate, and one low-pressure cylinder.

The valves belonging to the high-pressure cylinder are practically always piston valves. Piston valves are also generally used for the intermediate-pressure cylinder, but sometimes slide valves are used. Slide valves are generally used for the low-pressure cylinder.

Practically all marine steam engines are of the inverted vertical type; only a few have the cylinders and valves lying at an angle, as is the case with some paddle steamers.

Quite frequently the exhaust steam from marine steam engines is utilized in an exhaust-steam turbine which transmits its power to the main crankshaft by means of gears or chains.

Steam.—In the vast majority of cases, saturated steam is employed; but during recent years, superheated steam has come

Type of engine	High-pressure cylinder	Intermediate-pressure cylinder	One low-pressure cylinder	Two low-pressure cylinders
Single cylinder	Slide Corliss Piston Drop			
Twin: Two high-pressure cylinders side by side	Slide Corliss Piston Drop	(Colliery winding and haulage engines, steelworks rolling-mill engines)		
Triple: Three high-pressure cylinders side by side	Slide Piston	(Steelworks rolling-mill engines)		
Compound	Corliss	......	Corliss	
	Piston	......	Piston	
	Drop	......	Drop	
	Corliss	......	Slide	
	Piston	......	Slide	
	Piston	......	Corliss	
Triple expansion	Corliss	Corliss	Corliss	
	Corliss	Corliss	Slide	
Three cylinders	Corliss	Slide	Slide	
	Piston	Piston	Piston	
	Piston	Piston	Slide	
Four cylinders	Corliss	Corliss	Corliss	Corliss
	Corliss	Corliss	Slide	Slide
	Corliss	Slide	Slide	Slide
	Piston	Piston	Slide	Slide

into use very largely on the Continent, the maximum steam temperature at the engine stop valve being 650°F.

The *revolutions per minute* of marine steam engines are largely governed by considerations affecting the propeller efficiency and, therefore, do not vary much for engines above, say, 1,000 hp., being generally between 80 and 90 r.p.m.

In the case of launches, higher speeds are frequently used and with consequent lower propeller efficiency. Some large naval ships have been constructed with high-speed short-stroke engines, the maximum speed seldom, however, exceeding 130 r.p.m.

The various types of steam engines having now been classified, the subject will be treated under the following headings:

Steam.
Oil in Exhaust Steam and Feed Water.
Oil in Boilers.
Methods of Lubrication.
Lubricators.
Lubrication.
Deposits.
Lubrication of Corliss-valve Engines.
Lubrication of Colliery Winding Engines.
Uniflow Steam Engines (Stumpf Engines).
Marine Steam Engines.
Cylinder-oil Consumption.
Selection of Oil.
Testing Cylinder Oil.
Physical and Chemical Tests.
Use of Tallow Mixtures and Semisolid Greases as Cylinder Lubricants.
Lubrication Chart.
Locomotives.
Locomotive-Cylinder Oils.

STEAM

The range of steam pressure employed for different engines is given in the table on page 347.

Dry or Wet Saturated Steam.—When the steam leaves the boiler in a dry condition, it is called "dry saturated steam"; but under certain conditions, *e.g.*, when the boiler is forced above its normal capacity, or if the water level in the boiler is too high, the water boils violently; priming takes place, and the spray or foam from the water surface goes out with the steam, which in this condition is called "wet saturated steam."

It is in order to prevent the bulk of this water from being carried over with the steam that various so-called "antipriming devices" are frequently employed. If the steam pipe is long or not properly covered, a fair amount of steam will be cooled and condensed into water which is carried along with the steam toward the steam engine, together with any water that may have been carried over from the boiler. Therefore, the steam pipe should be covered with insulating material, to minimize conden-

sation. Water in the steam should be taken out, as far as possible, by a steam separator. But where the steam is very wet, it is difficult even with a good separator to prevent some of the water from entering the steam engine.

Superheated Steam.—Saturated steam, in passing through the heated superheater tubes, is heated above its saturated-steam temperature and becomes superheated steam.

The water that has been carried over from the boiler during periods of priming contains impurities, either solid impurities or salts in solution. When priming ceases, this water evaporates in the superheater, and the impurities will accumulate in the superheater tubes, in the form of a dry dust, which gets blown over with the steam into the engine and interferes with lubrication.

The *steam separator* tends to remove not only water but also rusty scale and impurities which are carried over from the boiler or which break loose from the inside of the steam pipes, also fine oxidized scale from the inside of the superheater tubes which gets carried over in the form of a fine black dust.

Cutting and scoring of cylinders, valves, and valve faces is sometimes experienced shortly after starting up a new engine. It is seldom due to lack of lubrication or to the quality of the cylinder oil used, but in most cases it can be accounted for by the steam line's not being properly blown through and cleansed from scale, foundry sand, rust, and the like. It is obvious that the entrance of such impurities into the steam engine will cause trouble, and the utmost care should be taken, when starting new steam engines, that the pipe lines from the boilers to the engines, as well as the internal spaces in the valve chests, cylinders, and steam connections between the cylinders, are thoroughly cleansed.

The importance of having a steam trap just before the inlet for the steam into the engine is not sufficiently appreciated by most steam users. If no steam separator be fitted, it is obvious that solid matters from the steam line or the boilers will have free access to the engine, which often results in the necessity for early repairing of cylinders and refacing of valves, etc.

OIL IN EXHAUST STEAM AND FEED WATER

A portion of the oil used for lubricating the steam-engine cylinders and valves will pass out through the valve- and piston-rod glands, but the greatest portion will leave the engine with the

exhaust steam and will be present in the form of oil in suspension or oil in emulsion.

Oil in suspension consists of oil globules which are fairly easily removed from the steam by the exhaust-steam oil separator. The globules of oil that are not extracted from the steam in the separator will, in the case of condensing engines, mix with the condensed steam and reach the hot well, where the greater portion will rise to the surface in the form of "float" oil which can be skimmed off.

A final safeguard may be provided in the form of a feed-water filter, the filter medium being cloth, sand, wood wool, etc., which will retain the globules of oil in suspension. The filter gradually becomes fouled with the oil, and the difference in pressure of the feed water on either side becomes greater and greater. If the fouling of the filter is allowed to proceed too far, the danger arises that the collected matter may be swept through and carried into the boilers. If a pressure gauge is fitted, it shows the difference in pressure before and after the filter; and the engineer will, from experience, soon become acquainted with the maximum difference in pressure permissible.

In marine practice the danger of the pressure's becoming too high is particularly great where the feed-water pump is directly driven by the main engines, as, in event of the engine's racing, the increased speed of the feed water will certainly tend to clear out the oil from the filter and carry it straight into the boilers.

Asbestos fiber is said to be capable of almost entirely breaking up the emulsified particles of oil and water and of thus extracting the greater portion of even emulsified oil, but, so far, experiments with such filtering material have not led to any practical solution of this question, as asbestos fiber is both costly to renew and costly to clean.

Oil in emulsion consists of minute particles of water (less than 1/50,000 in. in diameter) coated with an oil film. They are so fine that they float in the steam, and consequently the exhaust-steam oil separator will remove only a portion of the emulsified oil. The greater portion of the oil in emulsion, therefore, mixes with the condensed steam, which assumes a milky appearance. The greater the amount of oil the more milky will the water be.

Whereas oil in suspension is fairly easily removed in the hot well or in the feed-water filters, not so with the oil in emulsion.

The particles are so small that they will not rise to the surface in the hot well, and the filtering medium in the feed-water filter will not be able to retain them.

Exhaust Steam.—In *noncondensing* steam engines the steam passes out into the atmosphere, or it may be used for the purpose of heating the premises, for drying purposes, or for heating the feed water in feed-water heaters. The presence of oil in the heating or drying apparatus reduces its heating capacity considerably.

In condensing engines the steam, when leaving the engine, is condensed either by the jet- or the surface-condensing system.

Jet-condensing System.—The exhaust steam on entering the jet condenser meets numerous jets of cold water. The cold water condenses the steam into warm water, which by means of a pump is taken from the condensing chamber and delivered into the hot well, from which a small portion of the water is taken away by the boiler-feed pump for boiler-feed purposes. The bulk of the water, however, either is allowed to waste or, where only a limited supply of cooling water is available, it is passed through a cooling tower, where it is cooled, so that it can be used over and over again. A large portion of the cylinder oil will separate out and present itself as float oil on the surface, which can be skimmed off from time to time. There is generally very little chance of any cylinder oil's reaching the boilers where the jet-condensing system is employed.

Feed-water Heaters.—Such heaters are installed in numerous plants ashore, and generally they are what are termed "contact feed-water heaters" in which the steam comes in direct contact with the feed water.

Some oils form an emulsion with the water and do not separate out in the heater. The greater the quantity of water contained in the heater the easier it will be for the oil in suspension to separate; but to get the separation anywhere near satisfactory, it is necessary to use a pure mineral cylinder oil. Under no conditions should the oil be allowed to accumulate in large quantities in the heater, but it should be drained or skimmed off at suitable intervals.

It is also good practice to take the suction of the feed pump from a point as far below the surface as possible, because near the bottom the water is generally most free from oil. Limy deposits

which accumulate in the bottom of the heater should never be allowed to reach the level of the suction pipe.

Surface-condensing Plant.—The exhaust steam is here not cooled by direct contact with the cooling water but simply passes through the condenser chamber, in which are a great number of tubes through which cold water is forced. The steam is cooled, condensed, and pumped into the hot well, whence the boiler-feed pump takes the *whole of this water* and delivers it back into the boiler, where it is converted into steam and starts the circuit afresh.

All the oil contained in the exhaust steam will accumulate in the hot well, and the same remarks that were made in reference to contact feed-water heaters apply here as to skimming off the float oil and taking the feed water from a low level in the well. Also, here oil in emulsion will be carried through with the feed water and will enter the boiler unless eliminated by special means. Surface-condensing engines in land service are comparatively few in number but are used to some extent for electric-power installations and the like and, more especially, where town water is expensive; also for ice-manufacturing plants, when the condensed water is afterward used for ice production and where any trace of oil would make the ice cloudy.

Example 15.—A horizontal, 200-hp., cross-compound, condensing Robey engine was using a common black cylinder oil. The engine was surface condensing, and the feed pump discharged the water through a filter which was supposed to clear the feed water from oil. After passing this filter the feed water went direct to the boilers. The consumption of cylinder oil was found to be 4 or 5 drops per minute; and if the feed was reduced, the engine started groaning and grinding. In spite of all that, the makers of the filter claimed, oil was found in quantities in the boilers and was the cause of a most serious complaint from the insurance companies.

An examination of the boiler deposit showed that it was composed of black greasy matters and boiler scale. The boiler scale was partly carbonates, sulphates, and hydrates of lime and magnesium. After introducing a pure, mineral, *filtered* cylinder oil it was found possible to reduce the oil consumption to one drop in 70 sec., and it was reported that a marked improvement in

the boiler conditions took place at once, practically all the oil separating out in the hot well.

Extracting the Oil.—The oil may be separated from the exhaust steam by oil separators or extracted from the feed water by chemical or electrical treatment.

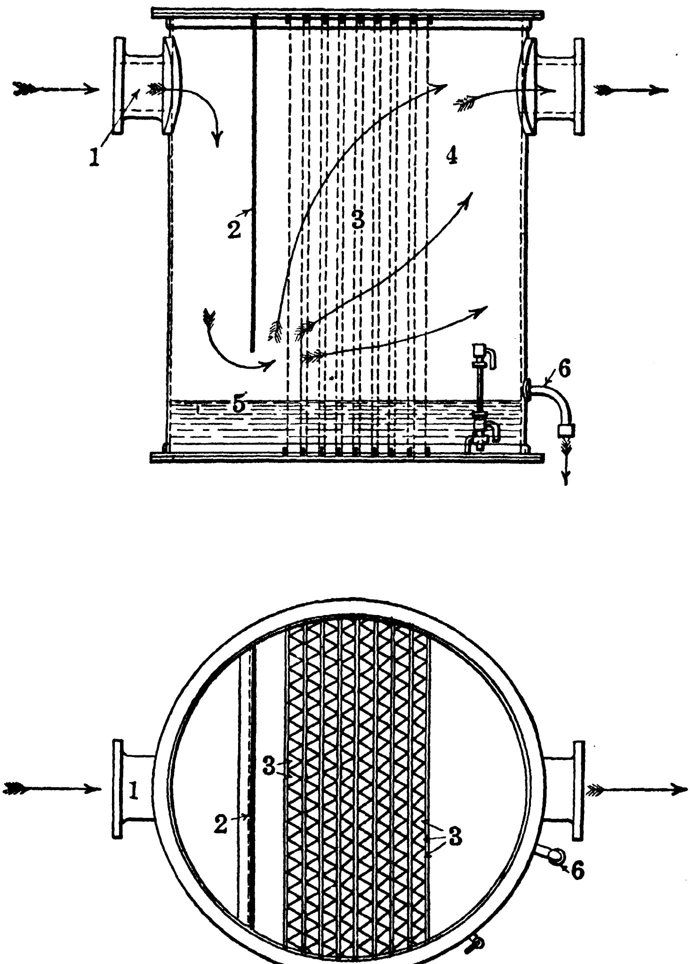


Fig. 139.—Baker oil separator.

Exhaust-steam Oil Separators.—Some exhaust-steam oil separators are very large reservoirs fitted with baffle plates, in which the exhaust steam loses its velocity, the oil and moisture separating out, mainly by gravitation, as in the Baker separator (Fig. 139).

The exhaust steam enters the separator through a branch (1) and is immediately caught and deflected to the lower part of the

separator body by the baffle (2). This baffle, besides deflecting the steam, also tends to retain such globules of oil and water as adhere to it owing to the impinging of the steam against its surface. These globules eventually collect and roll down the baffle (2), finding their way into the well in the separator bottom. A large free passage is provided under the baffle (2), which allows of a decrease in the speed of the steam so that, by the time the steam is passing through the cleansing angles (3), it is well expanded, and the temperature lowered, allowing an appreciable condensation to take place. This will be deposited on the angle bafflers in a chamber (4), whence the globules trickle down on to the surface of the water in the separator well (5), which is maintained at a constant level determined by the position of the oil pipe (6), through which the caught oil is discharged by gravitation if the steam engine is noncondensing. If it is a condensing engine, the oil must be pumped out by a small pump which should always be placed at least 24 in. below the bottom of the separator.

It has been found sometimes that, when *very high vacuums* are carried in steam-condensing plants, the exhaust steam is not freed from the oil and water contained. The cause of the trouble needs little seeking, as the air which is always contained in the condensing plant, and which constantly leaks into the system, expands rapidly with the higher vacuums. Accordingly, the velocity of the vapor containing the air is so great through the oil extractor that any oil or water present will be swept out from the separator. Where means are provided so that oil and water once taken out of the steam cannot again enter the flow, this effect of high vacuums is greatly minimized. This point has been kept in mind in other separators which are more compact and operate on the principle of splitting up the steam in many little steam flows, frequently changing their direction and trapping the oil by baffle plates which are so designed that, once the oil has been removed from the steam, it cannot be picked up again by the steam but gravitates to a reservoir in the bottom, whence it can be removed at intervals.

The *Princep oil separator* (Fig. 140) is a good example, illustrating these principles. The steam is allowed to expand and reduce its velocity so as to allow the solid and liquid particles to free themselves from the steam. A series of plates is suspended from the top. These plates are provided with a number of holes.

In each hole is inserted a ferrule projecting from 1/4 to 5/8 in. on each side of the plate. Through these ferrules are passed plates twisted to a pitch equal to the distance between each plate. The steam on entering the separator and passing through

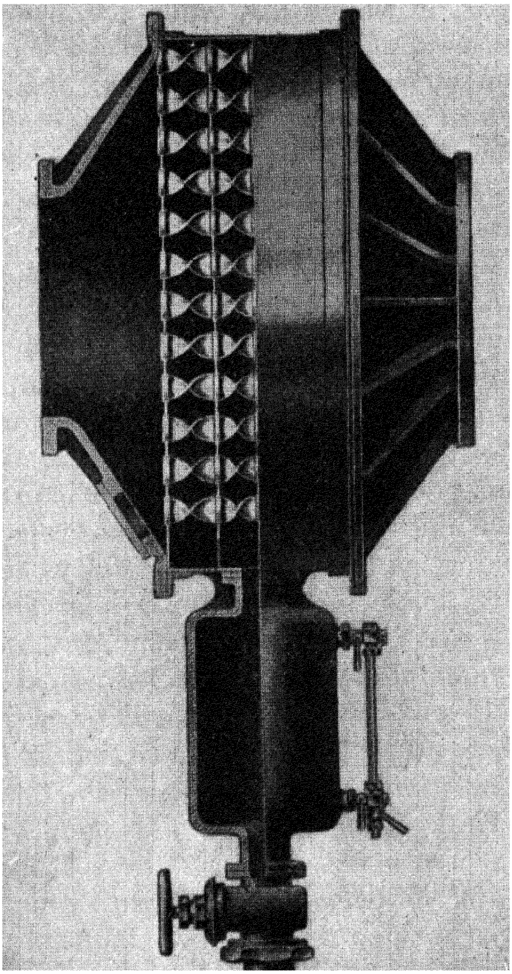


FIG. 140.—Princep's oil separator.

the holes strikes the twisted blade, which, being at an angle of 45 deg., deflects the oil and water on to the face of the plate. The continual action of the steam forces the deposit on the plate into the bottom chamber. It is impossible for any oil collected on the first plate to go forward to the second, because it is prevented from doing so by the ferrule which surrounds the hole. If the

first deflecting action has not abstracted all the oil and sediment from the steam, the next or third deflection in the next chamber will nearly always do so; but for safety's sake a few more plates are fitted.

The makers *guarantee that there shall be not more than $\frac{1}{3}$ gr. of oil* per gallon of water (condensed steam).

Feed Water. *Chemical Treatment.*—Oil in emulsion can be removed from the feed water by adding certain chemicals (alumina-soda process) which produce a flocculent precipitate. The large precipitated particles take hold of and absorb the minute particles of emulsified oil, so that subsequent filtration easily clarifies the water.

Feed-water softening and purifying plants are frequently in use where the greater portion of the feed water is taken from the town main or other source of fresh supply, yet in a great many large installations where surface condensing is resorted to, and where, therefore, only a small percentage of feed make-up is required, feed-water purifying plants may be installed with the main object of entirely freeing the water from cylinder oil. It becomes necessary in such cases to add a certain amount of water containing lime, so that, by virtue of the chemical processes, the oil may be thoroughly eliminated.

Electrical Treatment.—Another method is the electrical treatment in which the milky feed water containing the emulsified oil is passed through a tank containing two rows of iron plates; an electrical current is passed through the water, from one set of plates to the other. The result is that the minute particles of emulsified oil coagulate and combine with iron oxide (rust), produced from the plates, forming a heavy deposit which can be easily removed by subsequent filtration through a sand filter.

By this method it is possible to remove practically every trace of oil from the feed water. It is possible to guarantee less than 0.1 grain of oil per gallon, the consumption of electric energy being 1 Board of Trade Unit per 1,000 gal. of water treated.

Feed-water Softening.—If certain chemicals are added to *hard* feed water containing salts of lime, magnesium, etc., some of the lime and other ingredients are precipitated and are taken out in the form of sludge, whereas the remainder are transformed into such salts in solution as will not produce scale inside the boiler. In small plants a frequent practice is to add the chemicals to the

hot well or directly into the feed water on its way to the boiler or even into the boiler itself. In this case a great deal of sludge is produced which necessitates frequent "blowing down" of the boiler.

The best method of adding the chemicals is to have an independent feed-water softening plant, so that the water after treatment is pumped into the boiler in a condition as purified as possible, the sludge precipitated in the softening plant being removed by filtration.

Even if the feed water has been so treated that no scale is being formed in the boiler, it is obvious that, as only clean steam evaporates away from the boiler, the water will become more and more concentrated with salts in solution and inclined to cause priming, so that a certain amount of water should be blown out and replaced with fresh feed water, in order to keep the boiler water in good condition.

Feed water when treated is slightly alkaline; if it is excessively alkaline, the boilers prime, and the degree of alkalinity should therefore be kept as low as possible.

OIL IN BOILERS

As has been explained, oil may be introduced in the feed water either in the form of minute particles of oil kept in suspension or as minute particles of water coated with a thin film of oil (oil in emulsion).

When entering the boiler, the oil in suspension will rise to the surface more or less rapidly; and even if hardly appreciable quantities of such oil are introduced, it will almost invariably be noticed on the plates in the neighborhood of the water level. Much of this surface oil on the boiler-water level can be disposed of by judicious use of the scum cocks.

The presence of oil in emulsion is, however, much more dangerous, as the small particles of emulsified oil have only a very slight tendency to rise. They combine in the boiler water with the solid matter, such as carbonate of lime, carbonate of magnesium, and rust (which is always introduced with the feed water or comes from the boiler plates). Through this combination with these heavier solids, the state of affairs soon becomes this: that the combined particles have the same gravity as the water

and, accordingly, rise and fall with the eddy currents set up by circulation. They coat the underside as well as the upper side of tubes and flues and cling to the hot plates. The emulsified particles of oil which combine with the iron rust generally become so heavy that they sink to the bottom.

The greasy deposit on tubes and flues has the effect of immediately retarding the flow of heat through the plate. If the deposit contains a sufficient percentage of oil, the flow of heat may be retarded to such an extent that the plate becomes overheated, and the deposit begins to decompose, the layer in contact with the hot plate giving off various gases which blow the outer part up to a spongy, leathery mass, which by reason of its porosity retards the flow of heat even more than the thin greasy deposit. *The plate subsequently becomes heated to redness and, being unable to withstand the pressure of the steam, collapses.* At the same time the temperature has increased to such an extent that the oil is burned away from the deposit, leaving behind an apparently harmless deposit, containing the solid particles with which the oil originally became combined.

It has been found that new boilers with clean flues are more affected by oil than are boilers in which a certain amount of scale is present. Many cases have been known where *new* boiler furnaces have come down when the thickness of the coating of grease has probably been less than 0.001 in. A coating of oil of this thickness will increase the temperature of the boiler plates several hundred degrees Fahrenheit even with a moderate rate of evaporation.

A series of experiments was carried out by the late William Parker, engineer in chief to Lloyd's Registry, with a view to determining how far the conductivity of steel and iron plates is affected by oil films. His experiments proved that if an open steel dish were painted with three or four coats of greasy deposit taken from the bottom of a boiler in which a furnace collapse had occurred, mixed with a little cylinder oil, it was possible to burn the bottom of the dish before the water in it boiled.

When a boiler has become contaminated with oil, it should be washed out in the usual manner, then filled with water containing 0.5 lb. of soda ash per boiler horsepower. The water should be kept boiling at atmospheric pressure for 24 hr., then drawn off, and a thorough washing of the boiler should follow.

METHODS OF LUBRICATION

Points of Application.—In order to lubricate the internal parts of steam cylinders and valves, cylinder oil is introduced at one or several of the following points:

1. Direct to the steam chest.
2. Direct to the valves.
3. Direct to the cylinders.
4. Direct to the piston rod.
5. Feeding oil into the steam line.

1. *Direct to the Steam Chest.*—This is one of the earliest methods of application. In the case of slide valves, oil is usually introduced so that it drops directly over the valve face. In the case of drop valves or Corliss valves (Fig. 146*A*), it is usually introduced at two points halfway between valves and steam pipe (4). The flow of steam going to the right carries along with it the oil to the right-hand valve (6*b*), and the flow of steam going to the left carries the oil to the left-hand valve (6*a*). The oil after passing the valves enters the cylinder and provides lubrication for the piston (1); finally it reaches and lubricates the exhaust valves.

2. *Direct to the Valves.*—Oil is delivered at one point at the center of the Corliss valve or at two points, one at either end of the Corliss valve. It is the ends of the valve that require most lubrication, and feeding to the ends direct is therefore preferable to feeding at the center, in which case the flow of steam sweeps the oil right through the valve without any lubrication's reaching the valve ends. Piston valves are sometimes lubricated by two oil feeds in this manner, one feed to each end of the valve.

3. *Direct to the Cylinders.*—Sometimes, in the case of large engines, oil is introduced at the center of the cylinder or at the top or bottom; thus introduced, it is gradually spread by the piston over the cylinder walls.

4. *Direct to the Piston Rod.*—Oil is introduced direct to the piston rod externally, *i.e.*, outside the piston-rod gland, either by being dropped from a lubricator on to the piston rod or by an oil swab resting on the rod. The oil may also be introduced, particularly under conditions of high temperature and pressure, directly into the piston-rod gland itself, which gives a greater

METHODS OF LUBRICATION

Points of Application.—In order to lubricate the internal parts of steam cylinders and valves, cylinder oil is introduced at one or several of the following points:

1. Direct to the steam chest.
2. Direct to the valves.
3. Direct to the cylinders.
4. Direct to the piston rod.
5. Feeding oil into the steam line.

1. *Direct to the Steam Chest.*—This is one of the earliest methods of application. In the case of slide valves, oil is usually introduced so that it drops directly over the valve face. In the case of drop valves or Corliss valves (Fig. 146*A*), it is usually introduced at two points halfway between valves and steam pipe (4). The flow of steam going to the right carries along with it the oil to the right-hand valve (6*b*), and the flow of steam going to the left carries the oil to the left-hand valve (6*a*). The oil after passing the valves enters the cylinder and provides lubrication for the piston (1); finally it reaches and lubricates the exhaust valves.

2. *Direct to the Valves.*—Oil is delivered at one point at the center of the Corliss valve or at two points, one at either end of the Corliss valve. It is the ends of the valve that require most lubrication, and feeding to the ends direct is therefore preferable to feeding at the center, in which case the flow of steam sweeps the oil right through the valve without any lubrication's reaching the valve ends. Piston valves are sometimes lubricated by two oil feeds in this manner, one feed to each end of the valve.

3. *Direct to the Cylinders.*—Sometimes, in the case of large engines, oil is introduced at the center of the cylinder or at the top or bottom; thus introduced, it is gradually spread by the piston over the cylinder walls.

4. *Direct to the Piston Rod.*—Oil is introduced direct to the piston rod externally, *i.e.*, outside the piston-rod gland, either by being dropped from a lubricator on to the piston rod or by an oil swab resting on the rod. The oil may also be introduced, particularly under conditions of high temperature and pressure, directly into the piston-rod gland itself, which gives a greater

certainty of its being properly distributed, as, when it is applied externally, the greater portion is scraped off by the gland and runs to waste.

The four points of application so far mentioned are direct; *i.e.*, the oil is delivered as directly as possible to the moving parts requiring lubrication, and, speaking generally, the more directly the oil is fed the less satisfactory its distribution.

There is this disadvantage, that as cylinder oil is very heavy in viscosity, it spreads only with difficulty; it is apt to overlubricate some parts and not reach others. For this reason a great deal of oil is required in order to ensure that a complete lubricating film is maintained everywhere.

5. *Feeding Oil into the Steam Line.*—This is the best method of application and embodies an entirely different principle, as, instead of lubricating the various parts direct, the steam itself is charged with lubricant.

By the introduction of the oil into the main flow of steam, it is possible to make the steam carry the oil to all parts requiring lubrication; in fact, the steam itself is made a lubricant. The oil is introduced preferably on the boiler side of the engine stop valve and, in the case of saturated steam, should be introduced at least 18 in. away from the stop valve.

In the case of superheated steam, which does not carry the oil so well as saturated steam, it should be introduced not more than 18 in. before the engine stop valve. In cases where the superheat is very high and where the steam is carried around the steam cylinder before it enters the valves (usually drop valves) on the top of the cylinder, it is not practicable to introduce the oil before the engine stop valve, as it would be precipitated on the way; it is then introduced directly into the drop valves at a point where the flow of steam will break it up and distribute it in the steam passing through the valves every time that they open.

Atomizing the Oil.—It is, however, not sufficient to introduce the oil into the steam pipe or flow of steam, as it is then merely pushed along in the form of drops.

The best method, ensuring perfect distribution, is the atomizing method, by which the oil is introduced through an atomizer (Fig. 142) into the center of the flow of steam. The steam impinging with great velocity (from, say, 60 to 150 ft. per second) against the spoon-shaped end of the atomizer will squeeze the oil through

the slits in the atomizer, so that it is thoroughly broken up and, in the form of an exceedingly fine spray, mixes with the steam.

Various atomizers have been made for the purpose of splitting up the oil into minor particles; *e.g.*, it was made to ooze out from the perforated end of a tube, but the small holes (see Fig. 141)

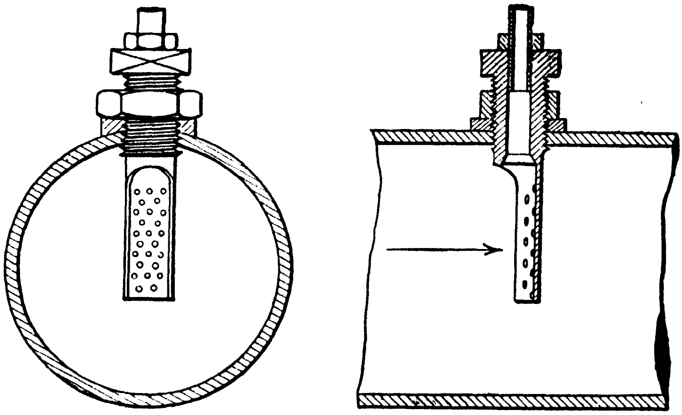


FIG. 141.—Atomizer.

divided the oil into drops only just small enough to pass through these holes. Other forms allowed it to be broken up over sharp edges.

After many trials, the author evolved the saw-slit type of atomizer illustrated in Fig. 142 (not patented). Its introduction has saved many thousands of barrels of oil and many thousands of horsepower which previously were wasted. When passing the slits, which should not be more than $\frac{1}{32}$ in. wide, the oil is well atomized, and entering the engine it lubricates

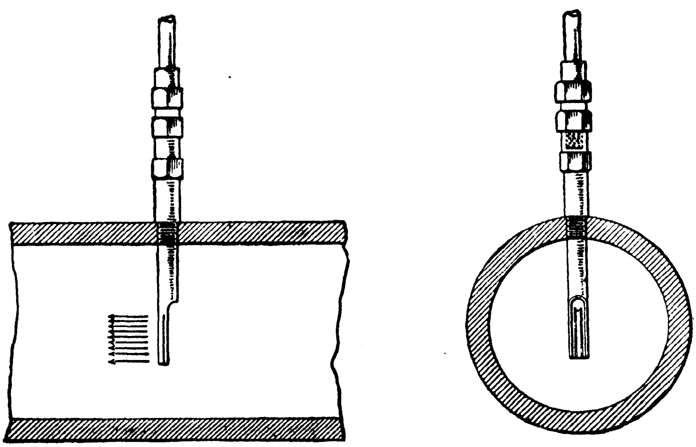


FIG. 142.—Thomsen's atomizer.

the spindle of the engine stop valve, making this valve easy to operate. It lubricates the steam valves and their spindles, the steam throwing down a slight portion of the oil on these points. The oil is thoroughly distributed in the form of a uniform coating over the piston, piston rings, and cylinder walls. The piston rod receives its proper share of the oil and accordingly lubricates the piston-rod gland packing from the inside, which is much more economical and efficient than lubricating the piston rod from the outside.

The exhaust valves receive their share of lubrication, and the exhaust steam, if it is carried over to the low-pressure cylinder (in the case of a compound engine) or to the intermediate- and low-pressure cylinders (in the case of a triple-expansion engine), will carry over finely atomized oil, so as to assist in lubricating these cylinders. Speaking generally, it will be found that when the feed of cylinder oil is ample for the satisfactory lubrication of the high-pressure cylinder, sufficient oil will be carried through to lubricate successfully the remaining cylinders.

If between cylinders of a compound or triple-expansion engine there are large receivers which may perhaps be utilized for reheating the steam, these receivers will act as oil separators, in which case it frequently becomes necessary to feed oil direct to the intermediate- and low-pressure engines; but this should be done by introducing it into the steam-inlet pipes leading to these cylinders, in preference to feeding it direct into the valves or cylinders.

Ordinarily, the oil feeds to the intermediate- and low-pressure steam pipes need be only from 5 to 25 per cent of the feed into the high-pressure steam main.

Figure 143 shows how the two feeds from a mechanically operated lubricator mounted on a compound steam engine introduce oil to the high-pressure steam pipe and low-pressure inlet pipe through atomizers carrying it into the center flow of steam.

Where a number of engines or pumps or a row of steam hammers, each separately lubricated, take their steam from the same main, admirable results may be accomplished, in the way of saving in oil consumption combined with better lubrication, through the employment of *one lubricator* mounted on the steam line a good distance away from the first unit (sometimes exceed-

ing 20 ft.) and feeding the cylinder oil through an atomizer into the central flow of steam.

The steam, as previously explained, acts as a carrying medium for the lubricant, and each unit gets a share of the oil in proportion to the quantity of steam passing through. Atomizing the oil and using the steam as the oil-spreading medium results in the most efficient distribution of the oil, so that not only is the friction reduced but also the quantity of oil required for full lubrication. As this method relies upon the velocity of the steam

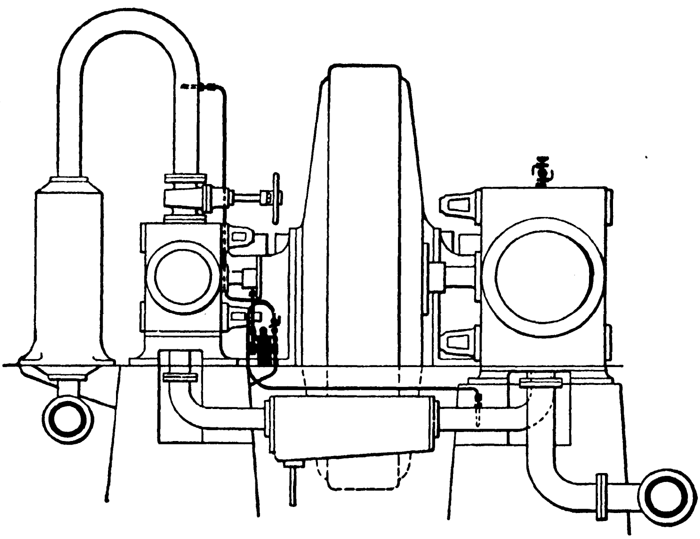


FIG. 143.—Two oil feeds for a compound engine.

to atomize the oil, it will be understood that only in very exceptional cases, where the velocity of the steam is too low, will it fail. This will be the case where the engines, for some reason or other, are operated at considerably less than half load.

When the oil is supplied *direct* to the various parts, it is very frequently found that the piston rod, particularly under high-pressure conditions, is poorly lubricated. The rod shows evidence of uneven distribution of oil; it looks scratched all over and has the peculiar raw-polished surface that indicates wear. Where in such cases the atomization method is introduced, the oil cups furnishing lubrication to the outside of the piston rod can usually be dispensed with, and, owing to the better lubrication of the piston rod from the inside, the surface of the rod will soon assume a glossy oily appearance, indicating that the wear has ceased and that the piston rod is getting a hard, polished skin.

When stopping for week ends or for long periods, it is good practice to give an extra-large quantity of oil for the last 5 min. that the engines are running. This will give a nice coating of oil to all the internal surfaces and prevent the formation of rust, which otherwise might occur.

Where the atomization method is introduced, it is not unusual to find that some of the joints between the point of entrance of the oil and the valve chest begin to leak, as some of the oil may dissolve deposits and dirt in the joints, which will therefore need to be tightened or repacked to keep steamtight.

Typical Results of Using the Atomization Method.—The cylinder oil should be introduced on a length of steam pipe with as few bends as possible before it enters the valve chest, and there must be no drains that might trap it. The importance of this point is illustrated in Example 17.

Example 16.—Four steam hammers were supplied with steam from the same main, and a sight-feed lubricator was mounted a good distance before the first steam hammer, while a drain pipe was fixed between this hammer and the lubricator. As long as all hammers were in full swing everything went well, but, when only one hammer was working, the flow of steam was so small that some of the oil was not properly atomized but dropped to the bottom of the pipe and was urged along it and, reaching the drain, dropped down.

After the position of the lubricator was changed to a place between the drain and the first steam hammer, no further trouble was experienced.

Example 17.—On a colliery winding engine a good grade of cylinder oil was used, the consumption being 1⅛ gal. per 24 hr. The oil was introduced into the steam pipe *but not through an atomizer.* The Corliss valves were grinding slightly. After fitting an atomizer, the grinding immediately stopped, and the consumption was reduced to ¾ gal. per 24 hr. work.

After 20 months' working under these conditions the toolmarks on the high-pressure cylinder were not worn away, and the colliery manager was satisfied that no other method of lubrication would have kept the cylinders in such remarkably fine order.

Example 18.—A cylinder oil of good quality had been in use for some time with only fairly good results on a Robey compound horizontal engine, the oil being introduced directly into the steam

chest by a sight-feed lubricator. When the oil was introduced 4 ft. away from the cylinder into the steam pipe from a mechanically operated lubricator, an inspection a few weeks later showed that great improvement had taken place. The internal wearing surfaces had a nice oily appearance, and no wear was noticeable. It was observed, when taking out the piston, that the threads of nut and piston-rod end were well lubricated, whereas before they used to be dry, and difficulty was experienced in getting the nut off.

Example 19.—Two Ruston Proctor horizontal cross-compound engines were lubricated with sight-feed hydrostatic lubricators, feeding cylinder oil into the valve chest of high-pressure cylinder. It was necessary to resort to "flushing" on the low-pressure cylinders through tallow cups which were placed on the center of the low-pressure cylinder barrels. After altering the feed to the steam pipe and employing an atomizer (in this case only 4 in. from the valve chest, owing to a drain in the steam line), the consumption of the same cylinder oil was reduced 25 per cent, and the "flushing" of the low-pressure cylinders was found to be unnecessary, as the oil, atomized, was carried over with the steam.

Example 20.—Some blowing engines on an ironworks had large D slide valves (42 by 48 in. outside dimensions) with 8-in. travel. Revolutions per minute of the engine, 40; steam pressure, 60 lb. per square inch; the steam superheated to 450°F. This engine was using ½-gal. of a *very viscous mineral cylinder oil* per 24 hr. run, and the slide valve at times jarred very badly. A compounded cylinder oil was then introduced, but although the valve worked better, yet it jarred badly at times, and the defect could be stopped only by a copious supply of oil.

After this *an atomizer was fitted*, and the working of the engine changed at once. The valves subsequently worked very smoothly, the engine giving no trouble, and the consumption of the same cylinder oil was reduced 30 per cent.

Example 21.—A colliery fan engine (large slide valve with expansion valve) used 8 gal. of cylinder oil per week through sight-feed hydrostatic lubricators and tallow cups.

These appliances were replaced by a mechanical lubricator, the feed entering flush with the inside of the steam pipe. This alteration made it possible to reduce the consumption of cylinder oil to 4 gal. per week. A further reduction was tried, but the

amount of oil had to be increased owing to the vibration of the eccentric rods, which indicated that the valves were insufficiently lubricated.

Another mechanical lubricator of an improved type was then fitted introducing the oil *through an atomizer* into the same place as before, the result being that the engines ran smoother than ever, and the oil consumption was reduced to only 1⅝ gal. per week.

Example 22.—On a large steam engine driving an air compressor it was found necessary to tighten the glands two or three times a week, when the oil was introduced direct into the valve chests. After the lubricator was altered to feed into the main steam pipe through an atomizer, *the glands required to be tightened only once in* 3 *weeks.*

Example 23.—A 350-hp. fan engine in a colliery consumed 3 gal. per day of common cylinder oil fed through three mechanically operated lubricators, having a total of eight oil feeds, feeding direct to the Corliss valves. In addition, it was found necessary to feed extra oil to the ends of two of the Corliss valves, in order to keep them silent.

A change was made, feeding a good-quality compounded oil into the high-pressure steam pipe through an atomizer, and the improvement in lubrication was immediately noticed. The two lubricators were discontinued; the consumption was gradually reduced to 2 pt. per day, and it was never found necessary to feed extra oil to the Corliss valves.

Example 24.—A two-cylinder horizontal rolling-mill engine was lubricated with a common straight mineral grade of cylinder oil internally and for the piston-rod guides. Grease was used on the crankpins, eccentrics, and main bearings. By the substitution of a good-grade compounded cylinder oil for the internal lubrication, introduced through atomizers; and an engine oil, specially suited to the work, on slides, eccentrics, crankpin, and main bearings a great reduction was made in the power required to overcome the friction in the engine.

With previous oils in use, the engine, with all load off, took 94.2 i.hp. Five weeks after, with the new oils in use, and under exactly similar conditions, the engine consumed only 41.4 i.hp., showing a reduction of 56 per cent in the power necessary to drive it with the rolls uncoupled. The average temperature of

slides above room was reduced from 33°F. with the old oil in use to 12.5°F. with the new oil, showing a reduction in rise in temperature, due to friction, of 20.5°F., or 63 per cent.

The cost of lubrication was reduced by 19 per cent with the better grade oils in use, the actual quantity of oil required being only one-third of that required with the previous oil.

The total number of indicator cards taken during both tests was 160, every set of cards being taken simultaneously, as all pencil motions were operated electrically.

Example 25.—Striking differences caused by lubrication may often be noticed on long-stroke, slow-speed reciprocating pumps, *e.g.*, Weir's or Woodeson's type. If a change in the cylinder oil is made to a better grade, or if the method of lubrication is improved, the change will immediately result in a greater number of strokes per minute and a smoother and more gliding motion of the rods, the reason being that from 25 to 50 per cent of the indicated horsepower is consumed by friction.

These examples show that a decided success has followed the combination of mechanical lubricators with atomizers and suitable grades of oil. The arrangement must, however, in each case be given due thought and consideration to ensure good results.

LUBRICATORS

The Tallow Cup.—The earliest form of lubricator is the tallow cup, consisting of an oil reservoir with a filling plug at the top and a cock at the bottom for emptying the oil from the reservoir into the cylinder or valve chest, etc. When the tallow cup is filled with oil, and the charge flushed into the engine, most of it will immediately drop to the bottom of the cylinder and be swept out with the exhaust steam, within the next few strokes of the engine. Then the engine runs on what little oil there may be left and within a short time will be running with no oil at all, until such time as the engine attendant considers it necessary to repeat the operation.

When the tallow cup is fixed on the valve chest, most of the oil never reaches the cylinder. It finds its way to the lower regions of the valve chest, mixes with any condensate that may be present, and is drained out.

The tallow cup still survives as an emergency lubricator for flushing purposes, when extra oil is required in places where no

oil feed is ordinarily provided for, such as top of cylinders or valve chests. Tallow cups are also still used for feeding oil to small steam pumps and the like.

As regards proper lubricators for feeding cylinder oil, two main types are in use: the hydrostatic lubricator and the mechanically operated lubricator.

Hydrostatic Lubricator (Fig. 144).—The lubricator is usually attached to the steam pipe and sometimes to the steam chest. Steam through pipe (1) enters the condenser (2) at the top of the lubricator. In this condenser the steam is cooled and condensed into water; when the valve (3) is open, the water is allowed to flow down through pipe (4) into the bottom of the oil reservoir (5). The incoming water displaces the oil and compels it to flow down through the pipe (6), through the adjusting valve (7) fitted for the purpose of regulating the feed; then the oil rises through the water in the sight-feed glass (8) and enters the steam pipe (10) through the delivery pipe (9).

The gauge glass (11) shows the level of the oil inside the container. The drain cock (12) is fitted for drawing off the water before the lubricator is refilled with oil through filling plug (13).

The distance from the steam inlet at the top of the pipe (1) to the top of condenser (2) should be at least 18 in. in order to get sufficient height of water to force the oil through the lubricator. Sometimes when a large oil feed is demanded, the pipe (1) is made in the form of a coil, so as to provide increased cooling surface for condensation.

When the lubricator is exposed to draft or to low temperature, which makes the oil sluggish, it is necessary to provide additional water pressure by means of longer piping above the condenser.

The lubricator must be started every time that the engine starts, and it must be stopped each time that the engine stops, or it keeps on feeding, and oil is wasted. In draining off the condensed water and in refilling the lubricator, a certain amount of oil is usually wasted.

The oil feed is affected by change in viscosity of the oil. It will therefore vary with the engine-room temperature and also every time that the lubricator is filled with fresh oil. The oil passes through small passages, which are liable to be partly choked with dirt, thus reducing the oil feed. For these reasons it is difficult to maintain a uniform feed with a hydrostatic lubrica-

tor, more especially where a very small feed is desired. A uniform feed of oil, however, is of great importance, as otherwise the steam is charged with either a large amount of oil—too much—or a small amount—too little.

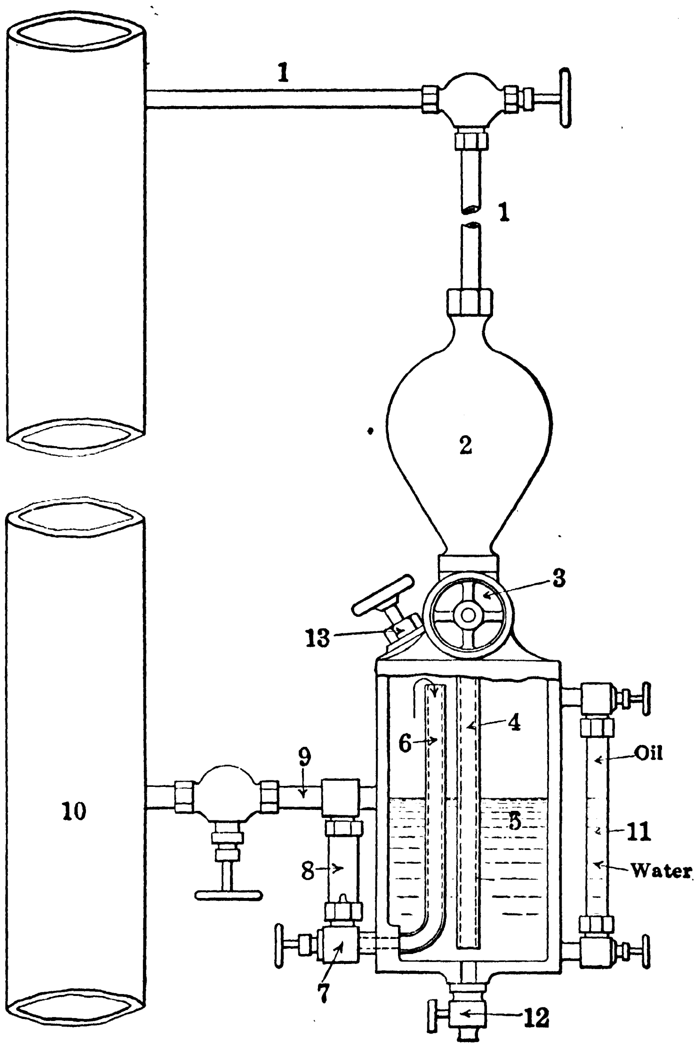


FIG. 144.—Hydrostatic lubricator.

In connection with hydrostatic lubricators the following points must be kept in mind.

When the sight-feed glass is inclined to get smeared with oil, this may be caused by the oil drops' being very large or the sight-feed glass having too small a bore. The remedy is to fit a wider glass or to solder a wire on to the feed nipple, so as to guide the oil

drops centrally, or to fill the glass with salt water or glycerin. The heavier specific gravity of these liquids causes the oil drops to rise earlier; *i.e.*, the drops are smaller and do not touch the glass.

Leakages of joints and packings must be avoided, as they interfere with the operation of the lubricator, which is very sensitive.

The lubricator must be filled completely with oil, and the condenser must be given time to fill up with water; otherwise steam will enter the oil reservoir and agitate the oil, and what is known as "churning" will occur in the sight-feed glass. When churning takes place the lubricator must be emptied, cooled, filled afresh, and time allowed for the condenser to fill with water.

The oil drops vary in size, according to the size of the nozzle, the gravity of the oil, and the liquid in the sight-feed glass; ordinarily it will be found that 1 gal. of oil will feed in 10,000 to 24,000 drops.

If the oil is fed by an unreliable lubricator, or if the oil feeds do not introduce the oil in the best possible manner, more oil is required to provide lubrication, and the lubrication will not be so efficient as when the oil is properly fed and applied.

True economy in the lubrication of the valves and cylinders is obtained by feeding the minimum quantity of the correct grade of oil to the working parts with such regularity as will ensure an unbroken oil film between the frictional surfaces. Such economy can never be secured by the use of a lubricator that feeds intermittently or irregularly.

The hydrostatic lubricator, which is still largely used in the United States, has in other countries been practically superseded by the mechanically operated lubricator.

Mechanically Operated Lubricators.—Mechanically operated lubricators are operated from some moving part of the engine; they therefore start feeding as soon as the engine starts and stop feeding when the engine stops, and they feed the oil in direct proportion to the speed of the engine.

Mechanically operated lubricators preferably have sight-feed arrangements for each oil feed, so that the exact quantity of oil passing through the various delivery pipes can be observed. These lubricators should be so constructed that each feed is independent, subject to separate adjustment and control. Also, the working parts should not be liable to wear, and—what is

especially important—all the working parts, valves, etc., should be easily accessible for inspection and cleaning.

In order to ensure that the oil pipes, from the mechanically operated lubricator to the various parts of the engine where oil is introduced, shall be always completely filled with oil, spring-loaded check valves should be fitted at their extreme ends. The pipes are thus always filled with oil, and lubrication is ensured instantly the engine, and therefore the lubricator, start to operate. These check valves should be of the combined check-and-vacuum valve pattern, in order to prevent the oil from being sucked out of the lubricator container when a vacuum is formed in the steam line during a standstill. If the oil is introduced into a steam connection where a partial vacuum exists, *i.e.*, before the low-pressure cylinder of a triple-expansion engine, it is essential that a valve of this description be fitted.

Care should be taken that the valve does not leak and that the spring is strong enough to keep the valve on its seat against the vacuum which tends to open it. The construction and operation of mechanically operated lubricators are treated in greater detail (page 88).

LUBRICATION

The internal moving parts, comprising valves, valve rods, piston, and piston rod, are exposed to the action of hot steam, and, with the exception of the valve rod and piston rod, none of the internal parts is exposed to view, so that the condition of lubrication cannot easily be ascertained. The internal lubrication of steam cylinders and valves is therefore of greater importance and more difficult than the lubrication of the external moving parts.

Slide Valve.—The flat surface of the slide valve rubbing against the valve face is difficult to lubricate, particularly in the case of large slide valves. In some cases, oil grooves are cut in the valve or in the valve face, in order to assist the oil in spreading all over the frictional surfaces.

The pressure between the valve and its face is great, particularly with "unbalanced" slide valves. Improper lubrication results in abrasion and cutting; excessive leakage of steam takes place and wipes away the lubrication film from the valve face, necessitating an increased consumption of oil. Excessive fric-

tion of the slide valve frequently makes the valve groan during operation, and the excessive resistance in moving the valve can usually be noticed by a trembling of the eccentric rod.

When the cover from the slide valve chest is removed and the slide valve is examined, excessive friction is always indicated by a dryness of the rubbing surfaces, showing wear and streaks of cutting where the metallic surfaces have eaten into one another. It is important that the cast iron in the valve and in the valve face should be of slightly different quality or hardness, as, if the quality is practically the same, they do not work well together.

Efficient lubrication of the slide valve produces a polished, glossy surface on the valve face. The valve operates without noise; the eccentric rod works smoothly, and when opened up for inspection the frictional surfaces show a complete lubrication film.

Owing to the large flat frictional surfaces of slide valves and to the difficulty of getting the oil thoroughly introduced between them, and, furthermore, owing to the great pressure between the valve and its face, it will now be understood why the use of slide valves is limited to steam pressures of, say, 125 lb. to the square inch, and a maximum steam temperature of, say, 450°F., and also why overloading always makes lubrication difficult. Experience has proved that when the oil is introduced into the steam and is thoroughly atomized, the oil gets much better distributed and has in many cases overcome groaning and trouble with slide valves where the direct methods of lubrication have failed to produce good results.

Corliss Valves.—The Corliss valve operates under conditions very similar to those of the slide valve, as it has a reciprocating sliding motion, only it oscillates over a cylindrical surface instead of moving over a flat surface.

Conditions of high temperature and high pressure, therefore, affect the lubrication of the Corliss valve in the same manner as they affect the slide valve. Bad lubrication is usually noticed when "feeling" the valve stems. As the admission Corliss valves are not positively operated during the closing period, bad lubrication may sometimes be indicated by the valves working sluggishly or even "sticking." Corliss valve engines are specially referred to page 385.

As Corliss valves do not work well with steam that is superheated more than, say, 100°F., Corliss-valve engines are less

frequently used nowadays, and drop-valve engines are being preferred.

Piston Valves.—There is but little pressure between the piston valve and its cylindrical sleeve, the pressure being mainly that exerted by the piston rings. Exposed to high pressure or high temperature, the piston valve expands uniformly, and the pressure between the piston rings and the sleeve remains the same. High pressure and high temperature, therefore, have little effect on the piston valve, nor are they themselves affected by overload, and consequently these valves can be operated under extreme conditions.

The signs of good or bad lubrication are similar to those indicated by slide valves, but, owing to its cylindrical balanced construction, the piston valve is easier to lubricate. It is important, however, that the oil be well distributed, and, again here, experience has shown that this can best be done by the atomization method of lubrication.

Drop Valves.—The drop valve lifts from and drops on its seat; consequently, no lubrication is required, except for the valve spindle, which usually is very long and has a very short motion in its guide. The clearance between the valve spindle and its guide is slight, so that it is important to have perfect lubrication.

The oil on the valve spindle is stagnant and exposed for a long time to the high temperature. It should be of the highest quality, so as not to bake into a carbonaceous deposit, which might cause sticking of the valve.

The oil should preferably be used sparingly and introduced by means of the steam, so as to be uniformly distributed.

Piston and Piston Rings.—In vertical steam engines there is no pressure between the cylinder and the cylinder walls, except that exerted by the piston rings. For this reason the lubrication of the pistons and piston rings in vertical engines is easier, and less oil is required than in horizontal engines, in which, besides the pressure between the piston rings and the cylinder walls, is frequently added the pressure of the weight of the piston sliding over the bottom of the cylinder.

In the case of large horizontal steam engines, the extra friction due to the weight of the piston is frequently avoided by extending the piston rod out through the back cover and connecting it to a tail-rod support. In this way, by making the piston rod suffi-

ciently rigid, the whole or part of the weight of the piston will be supported by the crosshead and tail-rod guides, so that the duty of the piston rings becomes only that of preventing leakage of steam from one side of the piston to the other.

In the case of horizontal steam engines employing highly superheated steam, this arrangement will always be found desirable and frequently necessary, as otherwise excessive friction and wear result. In tandem engines, the piston rod is for the same reasons usually supported between the cylinders.

The piston rings are always softer than the cylinder, so that if there is any wear, the greatest wear will be on the piston rings and not on the cylinder walls.

During recent years a number of piston rings have been introduced which exert pressure against the cylinder walls due to the action of internal springs. Where the conditions are ideal, these rings give good service, but they are somewhat rigid in their construction, so that where the movement of the piston from one end of the cylinder to the other is not absolutely central, experience has proved that these spring piston rings under extreme conditions have caused excessive friction and heavy wear.

It must be kept in mind that the temperature of the oil film is high and that excessive pressure or friction may easily destroy the film and produce bad results. For most conditions the old Ramsbottom type of split piston ring, which is very flexible, therefore still holds its own over a wide range of service.

It is always an advantage to have the corners of the piston rings rounded off, as, if they are sharp, they act like scrapers on the cylinder walls and destroy the oil film. When they are rounded, they do not dislodge the oil film, and better lubrication results.

The reason why modern piston packings of rather complicated constructions are not so widely used as one might expect will perhaps be found in the fact that in event of the center line of the piston and rod's not being quite coincident with the center line of the barrel, the flexibility of the piston packing may not be great enough to allow for this difference. This has led to an endeavor on the part of piston-packing makers and designers to embody in their design the quality known as "floating," which means that the particular type of packing in use may exert as nearly as possible even pressure all round against the walls of

the cylinder, quite independently and without affecting the piston body. This same experience has also led the makers of metallic packing for piston rods, etc., to allow the packing a little lateral movement from the rod, which prevents excessive friction and prevents distress of the packing and subsequent blowing.

Example 26.—The following is an interesting example illustrating how the various types of piston packing may have a bearing on the lubricating conditions. Complaints were made about a cylinder oil in use on an 8,000-hp., three-cylinder, horizontal rolling-mill engine, that excessive wear showed up in the cylinder, the cylinder walls appearing dry, no matter how much oil was used.

The engine had for several months been running on a very small consumption of cylinder oil and giving every satisfaction, the oil being fed into the three steam chests on the cylinders. The engine was hardly powerful enough to cope with the load. As the chief engineer had a suspicion that some portion of the steam was leaking past the pistons, the cylinders were rebored, and new pistons were put in fitted with a modern nonfloating type of piston ring, instead of Ramsbottom rings, which were employed previously. When the engine restarted, it was found to be worse than ever, and the output of the steelworks largely decreased. At the same time the coal consumption went up, and it was quite apparent that more steam was leaking past the pistons than under the old conditions. The reason why the nonfloating rings did not give satisfaction was that the axes of the cylinders were not coincident with the axes of the three piston rods and tail rods. Accordingly the piston rings at a certain part of the stroke were bearing hard against the cylinder barrels, setting up heavy friction.

At the same time, as the rings were not moving freely enough, steam was leaking past the pistons in enormous quantities. This will also explain why the cylinder walls were dry, as the steam oozing past the pistons would tend to carry away the film of oil on the cylinder walls. After some experimenting, new sets of piston rings were put in. These were of a type that allowed sufficient come-and-go (floating) to meet the conditions of the engine. After this, satisfactory results were again secured by the use of the same oil, a very marked improvement being

shown while dealing with the maximum load, and the coal bill fell to normal.

From the designer's point of view, there are several important things to consider in order to reduce the amount of power consumed by friction in steam-engine cylinders.

1. The weight of the piston itself should preferably be taken by means other than the wearing surfaces; in other words, *the piston should not be allowed to wear on the bottom of the cylinder barrel.*

2. The duty of the piston rings should be only to attain steam-tight working. That construction would be the best which accomplished this with the smallest amount of pressure between the piston rings and the cylinder walls. Furthermore, the construction should allow of a certain amount of come-and-go, as the coincidence of the center line of the piston and that of the cylinder barrel can never be depended upon in actual practice.

On opening up steam cylinders for inspection, the surface should present a rather dull apearance, coated with a thin film of oil. The presence of oil can be ascertained by striking a piece of paper around the cylinder bore at various parts of the stroke. After the oil film has been wiped off, the surface underneath should appear bright and glossy. If any wear has taken place, the surface will also be bright but in quite a different way; it will look silvery as if raw polished with fine emery cloth, and, although actual scoring may not have taken place, fine streaks will always be found, indicating wear. This may be due to a variety of causes, such as unsuitable or improperly selected oil; the lubricator may be unreliable, or the method of lubrication may not be satisfactory; or, possibly, the oil feed has been cut too low.

Packing Glands.—The function of the packing glands used for piston and valve rods is to prevent steam leakage outward in high-pressure cylinders and air leakage inward in low-pressure cylinders of condensing engines.

A perfect seal can be obtained only by the presence of a complete oil film on the rods, so that full and efficient lubrication of the packing glands is essential.

Many types of piston-rod glands are in service, but they can be divided into two main groups, *viz.:* those having soft and those having metallic packing.

Soft-packing Glands.—These are used only under saturated-steam conditions. The friction is always comparatively high; and

if the packing is screwed up hard, undue pressure is produced between the packing and the piston rod which results in scoring of the latter, after which it becomes difficult to keep the gland tight.

In reversible engines such as colliery winding engines and steelworks rolling-mill engines the reversing of the engines takes place by changing the position of the slide valves or piston valves in relation to the position of the pistons. This movement of the valves is done by hand in the case of small engines and by a special reversing engine in the case of large ones. It is obvious that the pull required to reverse the engine is influenced by the frictional resistance offered by the valves moving on their seats and the additional resistance of the valve rods moving in their glands.

Where the valve rods have been lubricated externally—a method that is wasteful and inefficient—a change to the atomization method of lubrication brings about a marked improvement, particularly noticeable in reversible engines. The valve rods will receive internal lubrication when inside the valve chest and, accordingly, will convey efficient lubrication to the packing, so that external lubrication can be dispensed with altogether.

The reversing lever will be easier to operate, owing to lower gland friction, and this is a point greatly appreciated by the engine drivers; in fact, every change in the grade of cylinder oil or in the method of application will be immediately noticed in the pull required to shift the reversing lever.

Metallic-packing Glands.—Figure 145 shows a simple design. Metallic packing is superior to soft packing. The gland friction with metallic packing is appreciably less than with soft packing, and there is much less danger of scoring's taking place.

It is essential when using metallic packing that the deflection and movement of the piston rod take place without setting up any undue pressures in the packing, which should exert only a slight pressure against the piston rod. This is accomplished by ball joints and annular "floating spaces" round the packing.

Metallic packing is always employed in the case of superheated steam and also in the case of high-pressure saturated steam in large engines.

When the atomization method of lubrication is employed with saturated or moderately superheated steam, it is frequently

unnecessary to lubricate the metallic packing direct. In the case of highly superheated steam, however, it is always necessary to have a direct feed of cylinder oil into the metallic packing. Only the highest grade of cylinder oil should be used for this purpose and should be fed uniformly and sparingly, as the excess oil remains stagnant in the casing, which holds the packing, and,

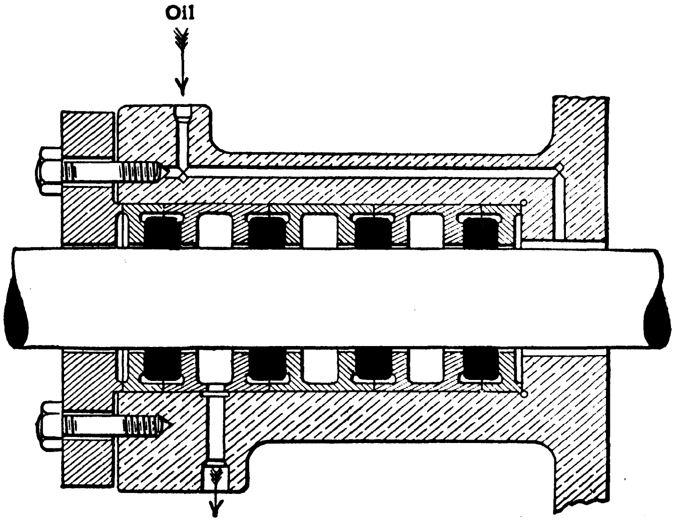


FIG. 145.—Metallic packing.

being exposed to high temperature, is inclined to bake into carbonaceous deposits.

DEPOSITS

Experience shows that in most cases where deposits develop in steam engines, the cause can be traced back to the boiler conditions. The deposit, if analyzed, will usually prove to be "boiler matters" amalgamated with a larger or smaller percentage of cylinder oil, decomposed oil, iron, and oxides of iron.

Deposits Due to Dirty Feed Water.—Where the feed water is taken from rivers, it should be taken from as clean a place as possible, and impurities should be prevented from entering the water supply. In rainy weather the rivers are swollen and muddy; and if dirty feed water is introduced into the boilers, they are apt to prime, and the impurities will be carried over with the steam and cause deposits.

In India the river water contains very fine suspended matter; this silt is carried over with the steam when the boilers prime and cause deposits inside the engines. It will appear that heavily

compounded oils have proved successful in preventing such deposit from caking and hardening, whereas with mineral or only slightly compounded oils the deposit becomes hard and very troublesome.

Example 27.—A 500-hp., horizontal, tandem, compound steam engine, using slightly superheated steam, had been lubricated satisfactorily with a good grade of dark cylinder oil. After an economizer breakdown, trouble immediately started, and a black deposit developed in the cylinders. The analysis was as follows:

	Per Cent
Water	6.0
Oil and volatile matter	43.4
Metallic iron, oxides of iron, lime, and traces of copper	50.6

It was found that the feed water was of very poor quality and contained a large quantity of impurities. However, as it passed the Green's economizer before it entered the boilers, the economizer pipes had the effect of precipitating the impurities in the lower bends, and the feed water was pumped into the boilers almost clean. A sample of impurities taken from one of the lower bends of the economizer piping was analyzed and showed a composition of oxides of iron, with a large percentage of carbonate of lime, silicates, and also traces of coal ash.

When the economizer broke down, the impure feed water was pumped direct into the boilers, and, on the boilers' priming, the steam carried the impurities into the steam engine, which explains the trouble.

While on the subject of superheated steam, it may not be out of place to mention the necessity for good control of the temperature of the steam.

Example 28.—In one case, trouble was experienced in a steam engine employing superheated steam, although the temperature of superheat, as indicated by the thermometer placed just in front of the engine stop valve, showed only 530°F.

When another thermometer was brought along it recorded a temperature 120° in excess of this, showing that the old thermometer, probably on account of the superheat's on occasions exceeding the normal, had been overheated. Such overheating will always produce a weakening of the bulb which means a lowering of the mercury in the stem, and *the thermometer therefore reads too low.*

Where a steam trap is not fitted or is of insufficient capacity, the boiler sludge will deposit in the corners and cavities of the valve chest, in the clearance spaces of the cylinder, behind the piston rings, etc. Where the oil is introduced into the main steam pipe and finely atomized, the greater part of the boiler sludge will be swept through the engine, and the valve chambers, cylinders, etc., will keep cleaner than where cylinder oil is applied direct.

The following example shows the importance of fitting a steam separator.

Example 29.—An oil of good quality had been used on a steam engine employing superheated steam and giving every satisfaction. Without warning, trouble began. The oil carbonized in the cylinders, and heavy wear of the internal surfaces was noticed. A sample of the black deposit was analyzed and contained the following constituents:

	Per Cent
Lime (carried over from the boilers)	Trace
Metallic iron and oxides of iron, principally metallic iron, produced by wear	56.4
Free oil	12.8
Volatile matter, chiefly carbonized oil	30.8

It was found that through an alteration in the pipe line some borings had dropped into the steam line and were urged along with the steam. The trouble continued for a considerable length of time, until the last boring had disappeared. Afterward no trouble was experienced, the same oil giving the satisfaction that it gave before.

Deposits Due to Impurities in the Steam.—The solid impurities in the steam are mainly two kinds:

1. Iron oxides (rust) from the boiler, superheater tubes, or steam line.

2. Boiler salts and boiler impurities carried over with the steam during periods of priming.

Rusty scale may come from the superheater tubes and the steam pipe. The cast-iron or steel surfaces in the tubes or pipes will in time be covered by a scale produced by oxidation, as there is usually a slight percentage of air mixed with the steam. Owing to the vibration of the steam pipes and to the expansion and contraction due to the temperature variations, this rust in time

breaks loose and is carried into the engines. The iron oxide from the superheaters is often in the form of a very fine black dust, whereas the rust from the steam pipe is more coarse. The impurities, whatever kind they may be, when entering the steam engine adhere and cling to the oil film all over the internal rubbing surfaces. The result is the formation of a dark-colored sludge or paste, which accumulates in the valves, valve ports, and passages; the spaces between and behind the piston rings; and on the piston faces.

In extreme cases the piston rings will be completely choked with deposits; they become inflexible in their grooves; they no longer perform their duty of preventing leakage of steam from one side of the piston to the other; and the result is excessive wear of the piston rings and the cylinder, also heavy loss in power due to the increased friction and steam leakage past the piston. The valves and pistons groan, and the various indications of excessive friction characteristic of the different kinds of valve motion will become apparent.

When using saturated steam, and particularly wet-saturated steam, the washing effect of the wet steam has a tendency to remove the deposits from the high-pressure cylinder and valves, but they are then frequently found in the passages leading from the high- to the low-pressure cylinder or in the latter.

Sometimes a liberal supply of oil or the use of a light-bodied compounded cylinder oil will temporarily relieve the distress of the engine.

In the case of superheated steam, the deposits formed in the high-pressure valves, valve chambers, and cylinders, particularly when very heavy-viscosity dark cylinder oils are used, remain there and are baked into hard, carbonaceous deposits, which are most objectionable and cause heavy wear. A liberal oil feed will only accentuate this trouble, as the excess oil simply decomposes and forms more deposits. The use of a light-bodied compounded filtered cylinder oil will frequently help to loosen the deposits and remove them from the high-pressure valves and cylinders.

In many cases where heavy carbonization has been experienced, great improvements have been brought about by introducing the atomization method of lubrication. It is obvious that, where oil is introduced direct to the various frictional surfaces, it takes time for it to spread; therefore more oil is required, and it is to this surplus oil that the impurities particularly adhere. Where

the cylinder oil is thoroughly atomized with the steam, it is spread to the best advantage over the internal surfaces; it presents only a thin lubricating film, and there is no surplus oil to which the impurities can adhere. Better atomization and distribution of the cylinder oil therefore not only results in greater economy but also means cleaner lubrication internally, *i.e.*, less formation of deposits.

Where the steam is very pure, carbonization seldom occurs when good-quality oils are used—even if the oils are fed *direct* and not atomized. If, however, the steam is dirty, the impurities adhere to the oil film, and because of the high temperature, a layer of oil carbon will be formed by oxidation. Later, a new layer of impurities will cover the layer of oil carbon, and another layer of oil will produce more oil carbon, so that if a crust of carbonaceous matter is examined, it will frequently be seen to consist of alternate layers of impurities and oil carbon.

Compounded filtered cylinder oils of good quality will produce practically clean lubrication, notwithstanding dirty steam; such oils prevent the impurities from caking together with the oil, so that they are swept out of the cylinder with the steam.

Where the feed water is treated chemically, and where a surplus of soda reaches the boiler, and priming occurs, even a small quantity of soda in the steam will have a very deleterious effect on lubrication. The soda dries up the oil film, and a more liberal oil feed is required when using saturated steam, whereas in the case of superheated steam a greater feed of oil will usually mean more trouble and increased formation of carbonaceous deposits.

When reheaters are installed between the high-pressure and lower stage cylinders, the oil may be carbonized in these reheaters; and if some of it is carried over, it will cause deposits in the intermediate- or low-pressure cylinders.

Example 30.—The following analysis of a deposit taken from the valve chest of a 1,000-hp. horizontal steam engine is typical of deposits due to priming of boilers.

	Per Cent
Iron and iron oxides	2.3
(This represents slight wear of the internal surfaces and rust carried to the engine from the steam line)	
Carbonate of soda, caustic soda, and carbonate of lime	44.2
(This has come from the boiler)	
Oil and volatile matter, chiefly oil	49.2
Water	4.3

Example 31.—On a colliery where the water used for boiler purposes was hard, the practice was to introduce soda directly into the boilers. Owing to this, and also to the fact that the boilers were worked rather at overcapacity, priming frequently occurred. It was found that when the steam was very wet and carried water containing boiler solids in suspension and various soluble salts, all these solids deposited themselves in the bottom bends of the superheater tubes, the water evaporating. When priming of the boilers ceased, the steam going through the superheaters carried the dry dust in the bottom bends into the steam engines, where the deposits had the effect of "drying up" the oil film, so that the piston rods appeared dry; groaning of valves and pistons was noticed and could be stopped only with a very copious supply of cylinder oil. This was introduced into the main steam pipe through atomizers. Owing to this, quite a large percentage of the deposit was swept through the engine with the exhaust steam and into an exhaust-steam turbine. The oil and the boiler solids deposited themselves on the turbine blades and necessitated frequent cleaning, at the same time decreasing the efficiency considerably.

When a feed-water softening plant was installed, the priming of the boilers was entirely overcome, and the troubles ceased.

A *chemical analysis of deposits* developed in steam engines will, as indicated in the examples, always be of service in tracing their cause. A very simple test which can easily be carried out is to take a portion of the deposit and burn it on a hot plate. The oil will burn away, and the residue, if consisting mainly of iron and rust, will indicate that rusty matters have been carried over to the engine or that wear is taking place; if the residue consists of chalky matters of a light color or of a yellowish-reddish color, it indicates priming of the boilers, the boiler salts being carried over with the steam into the engine. If the whole of the deposit burns away, it shows that the oil in use has produced oil carbon and that either it is an unsuitable quality of oil, or the oil is used in excess or is not distributed in the best possible manner.

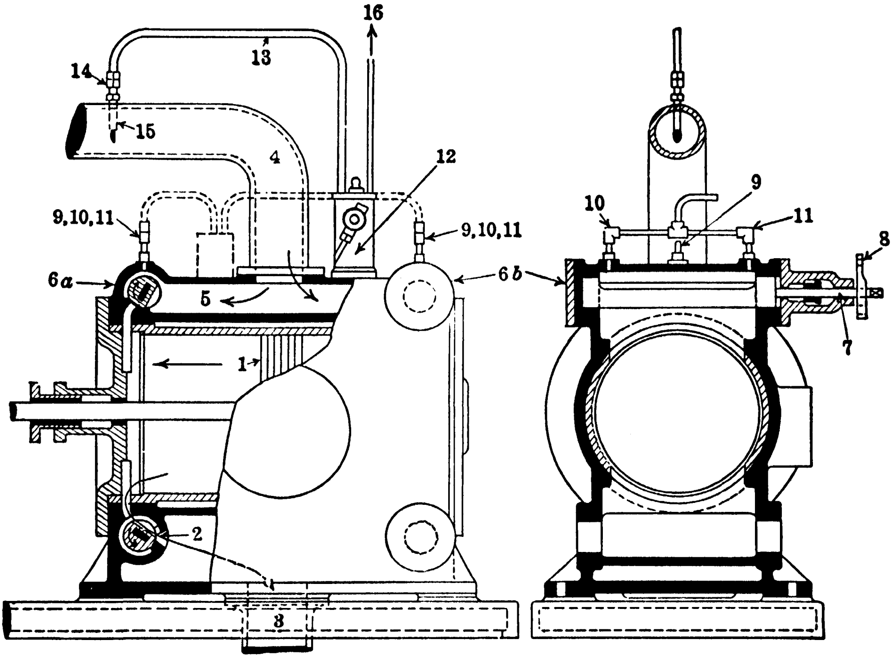
To avoid priming it is important that the feed-water softening plant shall be in good working order and that the tendency of the boiler to prime be overcome or minimized by keeping a proper water level, by keeping the water in the boiler in good condition,

and by having sufficient boiler capacity, so that the boilers are not overloaded.

LUBRICATION OF CORLISS VALVE ENGINES

In the following the lubrication of Corliss valves will be briefly analyzed.

Figures 146*A* and *B* illustrate the high-pressure cylinder of a steam engine having Corliss valves. The piston (1) is shown in



A *B*

Fig. 146.—Corliss valve lubrication.

Fig. 146*A* as moving toward the left, the steam being exhausted through the exhaust valve (2) to the exhaust pipe (3) leading to the low-pressure cylinder (possibly through a receiver). The steam coming from the steam pipe (4) into the valve chest (5) enters the cylinder, alternately passing the admission valve 6*a* or 6*b*.

Figure 146*B* shows a cross section of the cylinder and the valves. The admission valve (6*b*) is operated through the spindle (7) by means of the lever (8). The valve will require lubrication on the entire surface in contact with the valve face. How is this best accomplished?

The first attempt made to lubricate a valve of this description was by feeding the oil direct into the center of the valve, as shown by (9) (Fig. 146*B*). What happened, however, was this: The oil that dropped on to the center of the valve was immediately swept through the valve-port opening. Although the valve needed to be lubricated along its entire length, the oil was not given a chance to do so and succeeded in lubricating only a narrow strip of the valve and valve face just in the center.

A slight improvement on this system is feeding the oil at the points (10) and (11) instead of feeding it at the center. But in this case, also, the steam will sweep the drops of oil through the valve ports and prevent the oil from spreading over the entire valve face. The system is therefore not by a long way satisfactory, although it is advocated by the majority of engine builders.

Where, however, Corliss valves are very big, or where the steam is not very clean, or in cases of superheated steam, all sorts of difficulties and trouble may occur. The valves groan and wear. They may even stick, refusing to move, causing serious irregularities in the working of the engine. The cause of the trouble is bad lubrication, particularly of the two ends of the valves, the valve end rubbing hard against the end cover. It is quite evident that if it is difficult for the oil to remain on the middle part of the valve, it will be even more difficult for it to reach the two ends of the valves, where it is most needed.

Probably steam will constantly keep condensing and will reach the valve ends but will tend only to wash away any oil that may be present, except when the steam itself has been thoroughly lubricated and therefore practically becomes a lubricant. *In order to get the best results, the steam must be lubricated.* In the illustration, a double-feed mechanical lubricator (12) is mounted on the engine, actuated by some part of the valve mechanism, and discharging cylinder oil through pipe (13) leading to the check valve (14), the drops of oil trickling down inside the atomizer (15) being exposed to the central flow of steam.

In this way every drop of oil will be divided into thousands of the most minute particles and will be intimately mixed with the steam, so that when the steam is admitted through the admission valve (6*a*) or (6*b*) it sweeps over the valve faces and seats and will deposit sufficient oil to lubricate thoroughly. Furthermore, some of the oily steam will condense and carry oil to both

ends of the valves and to the valve end rubbing against the valve cover. Oil pipe (16) carries oil to the low-pressure cylinder.

Cases have been known where it was impossible to stop the groaning of a Corliss valve even with a feed of 120 drops per minute of good cylinder oil, and where the mere change of the oil feed from feeding "direct" on to the valve to feeding into the steam pipe had an almost immediate effect of silencing the valve —and doing this on a consumption of between 1 and 2 drops per minute. It is the old story over again, that "a drop of oil in the right place is better than a gallon on the floor."

If the steam has free access to one end of the valve, and the access to the other end is restricted, wobbling of *exhaust valves* may occur at each stroke of the engine. The cause for this will be readily understood.

Knocking of the valve-operating motions may be due to improper lubrication of the valves but may also simply be produced by a loose joint somewhere. This can easily be detected by flooding one bearing after another of the external motion with oil. When the bearing that caused the knocking is excessively lubricated in this way, the knock, which ordinarily is sharp, will be deadened, as the thicker oil film in the bearing will cushion the blow. Adjustment of the bearing in question should therefore generally overcome the trouble.

LUBRICATION OF COLLIERY WINDING ENGINES

The lubrication of colliery winding (hoisting) engines presents several interesting features. Many winding engines are internally lubricated by means of hydrostatic sight-feed lubricators feeding the cylinder oil either into the valve chest or valves or into the main steam pipe. Winding engines are generally horizontal twin steam engines, the main steam pipe branching off to each engine; and usually a sight-feed lubricator is mounted on each branch pipe between the throttle valve and its respective engine. As winding engines work intermittently, it will be understood that when sight-feed lubricators are in use *a good portion of the cylinder oil will be wasted,* as they continue to deliver oil during the periods when the engine is standing. As the sight-feed lubricators are generally mounted between the throttle valve and the engine, it will in such cases be found difficult to

operate the throttle valve, and the *valve stem will be found subject to more or less wear owing to lack of lubrication.*

Hydrostatic lubricators are seldom equipped with atomizers, so that the drivers of winding engines generally complain of difficulty in operating the reversing lever, owing to heavy friction in the valves and glands.

It will also be found that in order to minimize wear on the valve stems and piston rods it becomes necessary to swab the rods or to lubricate them through a sight-feed drop oiler, dropping cylinder oil on the rods outside the glands. This is, of course, very wasteful, *as most of the oil is scraped off the glands and runs to waste.*

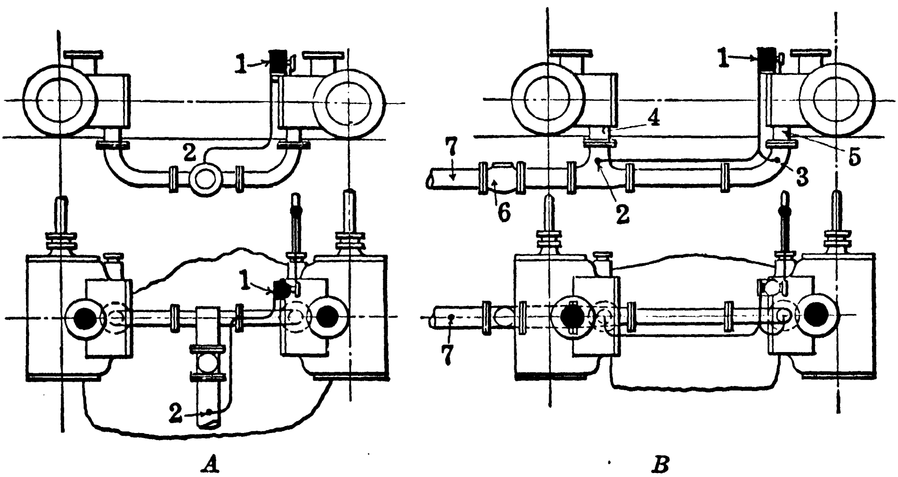


FIG. 147.—Lubrication of colliery hoisting engines.

When a mechanical lubricator is used feeding the oil into the main steam pipe before the throttle valve, through an atomizer, one oil feed will do to supply all requirements for the internal lubrication of throttle valve, reversing engine, and two cylinders, *if* the steam pipe comes to each cylinder by an equal branch, as in Fig. 147*A*, in which (1) is the lubricator feeding cylinder oil into the steam pipe at (2). But two feeds are necessary if the steam pipe is arranged as in Fig. 147*B*, for the greater inertia and density of the cylinder oil compared with that of the steam carries it past the branch pipe (4) of the near cylinder, most of the oil being carried to the right-hand engine.

Ordinarily, therefore, a two-feed lubricator should be fitted, feeding into the branches (4) and (5), respectively, at the points (2) and (3).

If it is considered necessary to lubricate the throttle valve (6) automatically, an extra feed can, of course, be put in to deal with the throttle valve at (7); but if this valve is of the equilibrium type, a swab with cylinder oil on the valve rod over week ends will suffice to keep gland and valve stem in good order.

The advantages resulting from this manner of applying the right grade of cylinder oil are many.

1. There is no waste of oil, as it is fed into the main steam pipe in direct proportion to the number of revolutions made by the engine. The lubricator stops feeding when the engine comes to rest.

2. As the oil is properly atomized and distributed throughout the body of the steam, the main stop valve and the throttle valve will be lubricated and therefore easier to handle, the wear will be overcome, and the reversing engine will need no separate lubrication.

3. Each engine will receive its portion of the oil required for satisfactory lubrication, and it will be found unnecessary to use the tallow cups which are often employed to give an extra dose of cylinder oil direct into the cylinders when the oil is not properly atomized.

4. As the steam is thoroughly lubricated, the valve rods and piston rods when coming inside the steam chest or cylinder will be coated with a good film of oil and thus receive their share of lubrication, which, in turn, will mean better lubrication of the gland packing, whether metallic or soft. Accordingly, less wear of the piston and valve rods will be apparent, and the packing will have a longer life. It will generally be found unnecessary to apply cylinder oil externally to the rods.

5. Owing to the better lubrication of the valve glands and of the valves, the reversing lever will be easier to operate; and this is a point greatly appreciated by drivers of winding engines.

6. Owing to the better lubrication, which means less power consumed in overcoming the friction, the engine drivers find that they can shut off steam earlier when the cage is nearing the end of its journey, and they also find that they can accelerate the engines and the cage more quickly or with less opening of the throttle valve.

Much the same remarks apply to steelworks rolling-mill engines, which also work intermittently and usually are reversing.

UNIFLOW STEAM ENGINES (STUMPF ENGINES)

The Stumpf engine has *one cylinder only;* steam of high pressure and high superheat expands right down to the condenser vacuum, the exhaust taking place through the piston's uncovering the exhaust port in the center of the cylinder.

There are thus *no exhaust valves;* the piston is very long, so that the exhaust ports are uncovered, only at the right moments. After the steam has been exhausted, and the piston moves back, it compresses the remaining steam, and the clearance space when the piston is at the end of its stroke is very small, the intention being that the compression should rise quite up to the boiler pressure.

As the steam always exhausts through ports in the center of the cylinder and always enters at each end alternatively of the cylinder, the temperature of the cylinder ends will be very high, and that in the center very low, the steam always flowing in the same direction—hence the name uniflow engines, as they are often called.

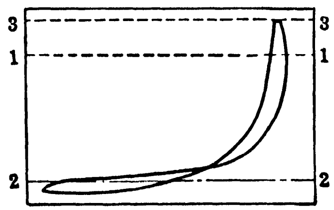


FIG. 148.—Faulty uniflow-engine diagram. 1. Boiler pressure. 2. Atmospheric line. 3. Maximum compression pressure.

The Stumpf engine will give the same efficiency as an ordinary compound engine using superheated steam.

Owing to the small clearance, great accuracy is necessary in manufacture and adjustment, and the valves must not leak.

The diagram (Fig. 148) is taken from a uniflow engine suffering from two faults, *viz.*, too small clearance (at that end of the cylinder) and leakage through the admission valve. It will be seen that the piston during the compression stroke compresses the steam that leaks in to a point far above the boiler pressure, partly because of the clearance spaces' being smaller than intended. The effect of this high compression is that the steam in the compression space is heated far above the normal temperature; it may reach as high as 700°F., which has a bad effect on the piston rod and the metallic packing. The piston rod may become so hot that the oil fumes and carbonizes badly.

The best method to lubricate the Stumpf engine is by a six-feed mechanically operated lubricator, distributing the oil feeds as follows:

1. One feed into the steam main before the stop valve, feeding through an atomizer.

2, 3. Two feeds, one into each of the vertical steam pipes, also through atomizers.

4, 5. Two feeds, one into each of the admission valves, as on light load the oil fed into the steam pipes will not be atomized and reach the cylinder in sufficient quantity.

6. One feed into the metallic packing of the piston rod.

As these engines run at a high speed, the oil from the crosshead is likely to be splashed on the piston rod and get carried into the packing where it carbonizes. It is, therefore, always advisable to use cylinder oil for lubrication of the crosshead and sometimes also for the guides, unless special precautions are taken for preventing the bearing oil from getting on to the piston rod (see Fig. 82, page 254).

MARINE STEAM ENGINES

Marine steam engines are often poorly lubricated. This is because, in times gone by, disastrous accidents and troubles with boilers have occurred when the cylinder oil used for internal lubrication has been carried into the boilers. Instead of endeavoring to obtain full lubrication and yet avoid boiler troubles, marine engineers have gone to the other extreme and have, except in the case of engines employing superheated steam, confined themselves to swabbing the piston rods and valve rods only, with a liberal supply of cylinder oil through the tallow cups, when acute trouble made it necessary to apply this remedy.

By the well-known practice of "swabbing the rods" most of the cylinder oil is scraped off by the glands and runs to waste, and only very little oil gets past the packings inside the engine, with the result that, at best, only the lower parts of valve chambers and cylinders are lubricated, and only very inefficiently.

Usually, the swab pot has an open top and is exposed to coal dust, dirt, and impurities, which may well give rise to trouble.

The virtue of well-lubricated valves and pistons is not only that the frictional losses are reduced but also that an oil seal is provided on the rubbing surfaces, which prevents or minimizes leakage of steam past the valves and pistons.

Marine engines employing superheated steam cannot operate without lubrication. Mechanically operated lubricators are

provided, which feed the oil into the main steam pipe or direct to the valves, cylinders, and packings; and if proper care is taken in selecting the correct quality of oil and in extracting it from the exhaust steam before it reaches the boilers, complete and efficient lubrication can be obtained without any danger of boiler troubles.

It would be desirable to employ this same system for marine engines using saturated steam. The quantity of oil required is very small indeed, and the best results are certainly obtained by feeding the minimum quantity of the correct grade of oil into the main steam pipe before the engine stop valve and with such regularity as will ensure an unbroken oil film between the frictional surfaces.

Extraction of Oil. *Exhaust-steam Oil Separator.*—Whereas exhaust-steam oil separators for a long time have been in very general use on steam-engine plants ashore, they have not yet gained the same universal favor among marine engineers. Exhaust-steam oil separators have, however, been designed which are compact and suitable for marine service.

If the bulk of the oil from the exhaust steam is removed by means of an oil separator, the result is that practically no oil is left in the steam to settle on the condenser tubes; this is a great advantage, as oily deposits in the condenser greatly impair its efficiency. It also means that the oil filters will more easily take care of the remainder of the oil and will not need cleaning so often.

Where the internal surfaces are well worn together, and a good skin produced, it is sometimes possible, without any apparent inconvenience or trouble (owing to the wet steam generally carried), to operate marine steam engines for long periods without internal lubrication; but the internal friction is considerably higher than when proper lubrication is employed, and the wear produced on the piston rings often makes itself apparent by producing sharp edges, so that the rings act as scrapers on the cylinder walls, producing heavy wear all round. Furthermore, *when no oil is used internally, the leakage of steam past the piston rings is often considerable.*

Example 32.—A remarkable instance was reported in *Power* for July 21, 1908. Four first-class armored cruisers of the U. S. Navy were put out of commission in a period of less than 10 months by burned-out boiler tubes. A thorough inspection

of the main engines showed that only a very ordinary amount of oil was in the exhaust steam. Examination of the auxiliaries, however, disclosed the trouble, which was located in the exhaust from six 100-kw.-capacity lighting sets, which were in operation day and night. No lubrication was used in the cylinders, but a careful test showed the presence of 2.2 oz. of oil per hour in the exhaust from each engine. These engines were of the forced-lubrication enclosed type, and the oil was drawn up from the crank chamber and crept along the piston rods into the cylinders. When this trouble was overcome by lengthening the distance pieces between the cylinders and the crank-chamber top, and no oil was found any longer in the exhaust from these engines, *a great drop in the economy was at once noticed*, the steam consumption increasing to 36.3 lb. of steam per kilowatt-hour, whereas under the old conditions the engines had passed the U. S. Navy requirements of "a steam consumption not exceeding 31 lb. per kilowatt-hour," without lubrication of the cylinders.

However, as has been explained, the cylinders were really getting lubrication, although the oil was only a light-bodied oil from the crank chambers. A series of tests was then made on one of the redesigned engines, to determine the effect upon the economy of varying quantities of cylinder oil. The trials showed that when the oil feed was cut very fine, the consumption of steam per kilowatt-hour increased rapidly. The lowest steam consumption with ample internal lubrication was found to be 29.7 lb. per kilowatt-hour, compared with 36.3 lb. per kilowatt-hour when the engines were operating without internal lubrication. The difference in the steam consumption is due partly to increased consumption of power to overcome the internal friction and partly to the heavy leakage of steam past the piston rings due to the absence of the oil film. Furthermore, when the film of oil is not present on the cylinder walls of steam engines, radiation of the heat from the steam more easily takes place, the oil film being a bad conductor of heat.

These trials show very clearly that the economy of a reciprocating vertical engine is to a very great extent dependent upon proper lubrication of the cylinders.

When this is the case with vertical engines, it is obvious that proper cylinder lubrication is still more important with horizontal steam engines.

CYLINDER-OIL CONSUMPTION

The oil consumption is dependent upon many conditions which will be briefly referred to in the following.

Large engines require less cylinder oil per brake horsepower-hour than small ones.

Horizontal engines obviously need more cylinder oil than *vertical* engines, but care should be taken not to *underfeed* the latter, even if they do not "complain," as it means extra friction and loss of steam through leakage.

Large engines without tail rods require more oil than when tail rods are fitted, which relieve the pressure between the piston and the cylinder.

Steam Pressure and Temperature.—The greater the steam pressure the higher the temperature; but when oils are chosen to suit the temperature, the oil consumption cannot be said to be influenced by the steam pressure or the steam temperature.

Superheated steam does not, as many appear to think, mean an increased oil consumption; speaking generally, it may be said that the consumption for engines employing superheated steam, other things being equal, need not be more—in fact, may be slightly less—than with dry-saturated steam. Where the steam is dirty, the oil *must* be applied in the best possible manner and as *economically* as possible.

Saturated Steam.—Wet-saturated steam means an increased demand for cylinder oil, quite independent of whatever kind of impurities may enter with the wet steam.

The oil-consumption figures given below in grams per brake horsepower hour may be considered approximately correct for average conditions. The higher figures in each case apply to smaller engines or wet-steam conditions, while the lower figures

CYLINDER-OIL CONSUMPTIONS IN GRAMS PER BRAKE HORSEPOWER-HOUR

Steam engines, horsepower	Engines	
	Horizontal	Vertical
Below 400	1.0 to 0.3	0.6 to 0.15
Above 400	0.6 to 0.15	0.4 to 0.05

apply to larger engines or engines employing dry or superheated steam or vertical engines—marine engines in particular.

SELECTION OF OIL

The object of internal lubrication in a steam engine is (1) to form a *lubricating film* between the rubbing surfaces and thus replace the metallic with fluid friction as far as possible; (2) to form *an oil-sealing film* in order to prevent leakage of steam past the valves, pistons, and gland packings.

Only by feeding the *correct grade of high-quality cylinder oil, specially selected to suit the operating conditions* of the engine, *applied in the correct manner, to the right place* and *in the right quantity,* will the steam engine continue to operate at its highest efficiency and with the minimum cost of renewals and repairs.

Perfect lubrication is therefore dependent chiefly on the *methods of lubrication employed* and the *selection of the correct oil* for each individual case.

If *too much oil* is used, lubrication under saturated-steam conditions will not be any better than when the right quantity of oil is used; whereas under superheated-steam conditions, the excess oil is detrimental, leading to the formation of carbonaceous deposits.

If *too little oil* is used, a satisfactory oil film will not be maintained between the frictional surfaces, so that not only will heavy friction and wear occur but also excessive steam leakage.

There are a few vertical engines employing saturated steam which can be operated without the use of cylinder oil and without groaning. Nonlubrication will, however, mean excessive friction and excessive leakage of steam past the moving surfaces, which will be worth many times the cost of good lubrication.

If an *oil too heavy* in viscosity is used, it will not atomize readily, resulting in poor distribution and necessitating excessive consumption. Because of its heavy body, the fluid frictional losses will be higher than they need be; and if the steam carries over impurities to the engine, the use of such an oil will encourage the accumulation of deposits, particularly under conditions of high pressure and superheat.

If an oil *too light in viscosity* is used, it will readily atomize and distribute itself, but it will not be able to withstand the pressure between the rubbing surfaces; metallic contact will take place,

resulting in excessive wear; also, excessive leakage of steam will occur, owing to the rubbing surfaces' not being completely oil sealed.

With the *right-quality oil* in use, correctly selected for the conditions and applied in right quantity, a satisfactory lubricating film will be maintained on all the internal surfaces. This film will be maintained with a lower consumption of oil than with any other grade of oil. Therefore the cost of lubrication will be low, and the frictional losses, because of the fluid friction of the oil itself as well as the leakage of steam past the moving surfaces, will be reduced to the minimum.

For conditions of high pressure and superheat, the use of the right-quality cylinder oil will also mean that, rightly applied and in the right quantity, the danger of the formation of carbonaceous deposits will be minimized, and the possibility of excessive wear much reduced.

In the following pages will be examined the conditions influencing the selection of the correct grade of cylinder oil, *viz.*, steam pressure, size and construction, superheat, wet steam, load, impurities, exhaust steam.

Influence of Steam Pressure.—High steam pressure means high temperature, so that, generally speaking, heavy-viscosity oils are used for high steam pressures, and low-viscosity oils for low steam pressures (low-pressure cylinders in particular).

Influence of Size, Speed, and Construction.—The weight of a piston increases very nearly as the cube of its diameter, but its bearing surface more as the square, so that large pistons in horizontal engines, when they are not supported by a tail rod, require very heavy-viscosity oils. Smaller pistons and all vertical cylinders, other things being equal, will be best served with lower viscosity oils. High piston speed, which is found in most modern engines, particularly superheated-steam engines, demands lower viscosity oils, so as to minimize the oil drag on the pistons.

Influence of Superheated Steam.—When steam of moderate superheat is used, it will enter the high-pressure cylinder in a dry condition; but during the expansion of the steam in the cylinder it will cool, and, toward the end of the stroke, condensation will occur.

In the case of highly superheated steam, it is of the greatest importance that the oil should be thoroughly atomized in the

body of the steam. There is no condensation, therefore no washing effect on the cylinder walls. The oil remains a long time in the high-pressure cylinder, exposed to friction and heat; while, therefore, only a small quantity of oil is required, it should be of such a nature that it will withstand the heat without appreciable decomposition and resultant formation of carbon.

Dark cylinder oils exposed to heat will form more carbon than filtered cylinder oils. The coloring matter, which is extracted during the filtration process, consists of very high-specific-gravity bituminous matter (hence the reason why filtered cylinder oils have low specific gravities), which evidently decomposes and forms carbon.

It has been asserted by oil firms that dark cylinder oils are better lubricants than filtered cylinder oils. They are, as a rule, more *viscous*, which may perhaps excuse this fallacy of opinion, but a moment's reflection will make it obvious to anyone that the chief difference between filtered and dark cylinder oils is that the latter contain bituminous coloring matter, the greater portion of which is removed when filtered cylinder oils are manufactured; in other words, that the higher viscosity of dark cylinder oils is due largely to sticky nonlubricating ingredients, which are liable to decomposition if exposed to heat and other influences.

As regards compounding superheat cylinder oils, the author recommends a small percentage, say 4 to 6 per cent of acidless tallow oil, for most conditions of superheat, as the fixed oil improves lubrication appreciably.

The oil becomes very thin owing to the high temperature, and the fixed oil improves the oiliness of a straight mineral oil; its presence is therefore nearly always desirable. No ill effects have ever been known to be caused by decomposition (formation of fatty acid) of such a small percentage of fixed oil. On the contrary, it will tend to prevent carbonized matter from baking together and forming hard crusts, in this way making the nature of such deposits less dangerous.

Influence of Wet Steam.—Where the steam is wet it has a tendency to wash away the oil film on the internal surfaces. In compound or triple-expansion engines, even if the steam is dry on entering the high-pressure cylinder, the fall in pressure and expansion taking place produces condensation, so that the steam arriving at the low-pressure cylinder usually is very wet.

It is obvious that the problem of lubricating the high-pressure cylinder under dry-steam conditions is different from lubricating the high-pressure cylinder under wet-steam conditions or from lubricating the low-pressure cylinders under very wet-steam conditions.

In order to lubricate cylinders satisfactorily under wet-steam conditions, the cylinder oil must readily combine with the moisture and cling to the cylinder walls; *i.e.*, it must be a *compounded* cylinder oil. It is therefore frequently desirable to use one grade of cylinder oil for the high-pressure cylinder and a different grade (lower viscosity, more heavily compounded) for the low-pressure cylinder in large compound or triple-expansion engines.

Influence of Engine Load.—The greater the engine load the greater the volume of steam passing through the steam pipe into the engine; and the higher its velocity the better will it be able to break up the cylinder oil introduced through the atomizer.

As superheated steam does not atomize and distribute the oil so well as does saturated steam, engines employing superheated steam and likely to operate under light load conditions should have means for lubricating the internal parts direct in addition to introducing the oil where it can be atomized. Light load also means that the steam expands more in the high-pressure cylinder, so that at the end of the piston stroke the steam is much more moist (more condensation) than under full-load conditions. Wet steam calls for compounded cylinder oil, so that, speaking generally, light-load conditions demand *compounded oils of low viscosity*.

Influence of Impurities in the Steam.—It has already been mentioned how iron oxides, boiler salts, etc., have the effect of combining with the oil and forming deposits. The higher the viscosity of the oil the more difficult will it be to avoid such deposits, as such oils cling tenaciously to the impurities. Low-viscosity oils are therefore to be preferred, where a great deal of impurities enter with the steam; this is particularly the case under conditions of superheat.

As the presence of impurities in the steam usually means that priming of the boilers is responsible, in the first instance, the steam will be wet, so that oils heavily compounded are, as a rule, called for. There is one exception to this rule, *viz.*, that under conditions of high superheat, where it is only the *dry*

boiler salts that reach the engine, and where these dry salts contain alkali, *e.g.*, soda, they will form a soap with the tallow oil present in the cylinder oil, which will aggravate the deposit trouble, whereas with a straight mineral oil such soap cannot possibly be formed.

For saturated low-pressure steam conditions, there is no *great* difference between dark or filtered cylinder oils as regards formation of deposit by impurities; but for superheated steam conditions, filtered cylinder oils are vastly superior, as, under the dry high-temperature conditions, the bituminous matter in dark oils combines with the impurities, decomposes, owing partly to oxidation, *e.g.*, oxygen being taken from the iron oxides, and forms hard brittle carbon.

Generally speaking, the presence of impurities under saturated-steam conditions therefore calls for oils of *low viscosity* and *compounded* (filtered oils not particularly needed), whereas impurities under superheated-steam conditions demand mineral oils of *low viscosity* and *filtered* (compounded oils may form soap).

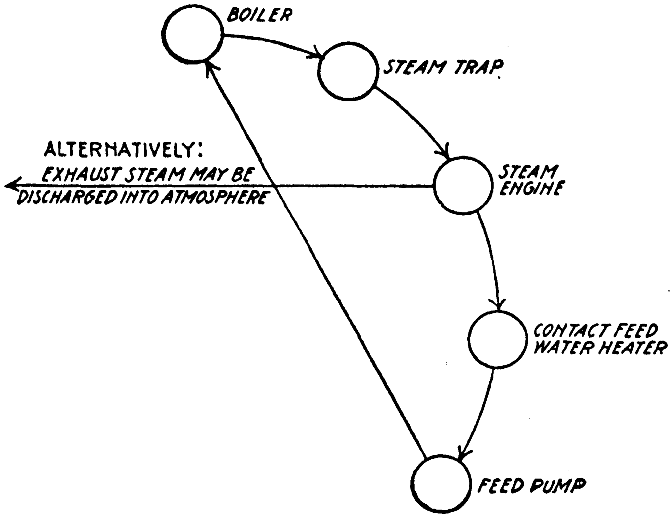
Influence of Exhaust Steam.—As mentioned elsewhere, it is under certain conditions desirable to extract the oil from the exhaust steam and to eliminate as far as possible the danger arising from its getting back into the boiler. All compounded cylinder oils are difficult to separate from the exhaust steam and from the feed water. All straight mineral oils are fairly easy to extract, but the dark oils combine rather intimately with the water, forming semiemulsified clots of oil (which cannot be used again), and just a trace of the oil goes into a fine emulsion.

Well-filtered straight mineral oils separate easily from the feed water, and the oil can be recovered and used on less important work; the feed water will be practically free from emulsified oil.

It will, however, be found that more oil is required when using a straight mineral cylinder oil than when using a compounded cylinder oil, so that the best results will often be produced by using a slightly compounded filtered oil, as such an oil will give more efficient and more economical lubrication. The oil should be fed as economically as possible, so that there will be only a small quantity present in the exhaust steam. Diagrams 1 to 6 may prove of interest in connection with the influence of exhaust steam on the selection of oil.

DIAGRAM 1

SMALL NONCONDENSING LAND ENGINES

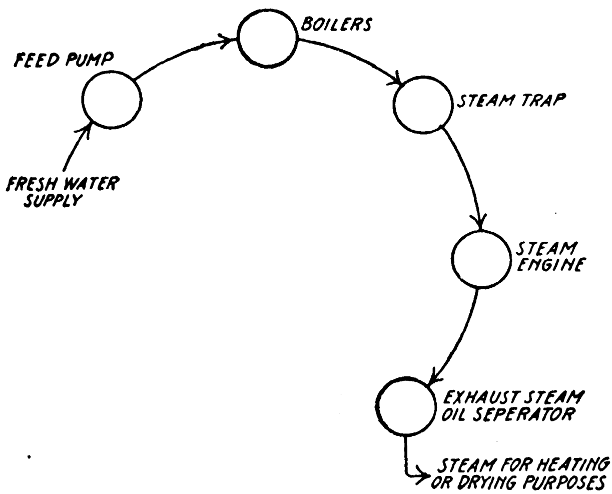


When the exhaust steam is discharged into the atmosphere, the cylinder oil may be chosen entirely with a view to suiting the engine requirements.

When a contact feed-water heater is fitted, straight mineral, dark, or filtered steam-cylinder oils must be used.

DIAGRAM 2

LARGER SIZE NONCONDENSING LAND ENGINES

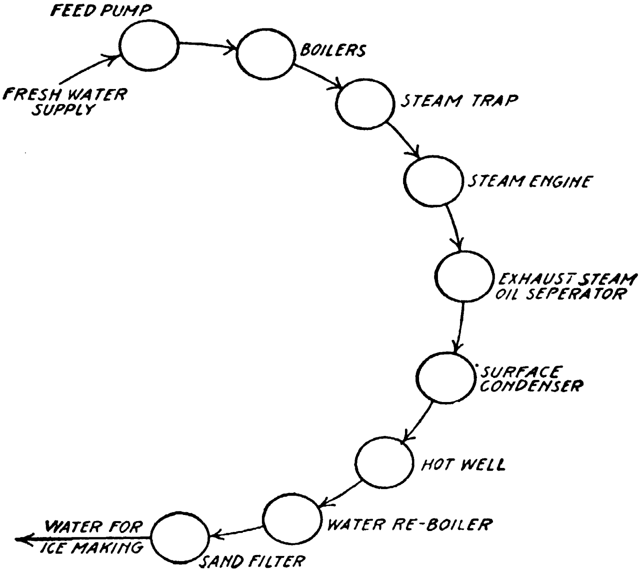


Straight mineral, dark, or filtered cylinder oils must be used, or filtered oils, slightly compounded, used very sparingly.

With some vertical engines, aquadag has been used successfully, and the condensed steam from the heating system returned to the boilers.

Diagram 3

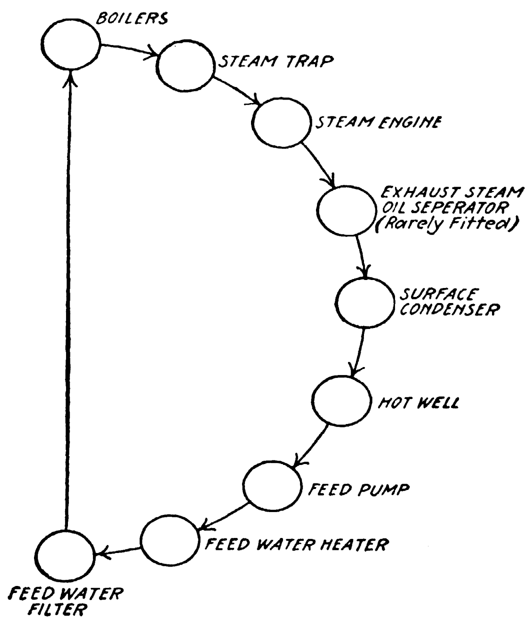
Surface-condensing Engine in Ice-making Plants



Straight mineral, dark, or filtered oils must be used, or filtered oils, slightly compounded, used very sparingly.

Diagram 4

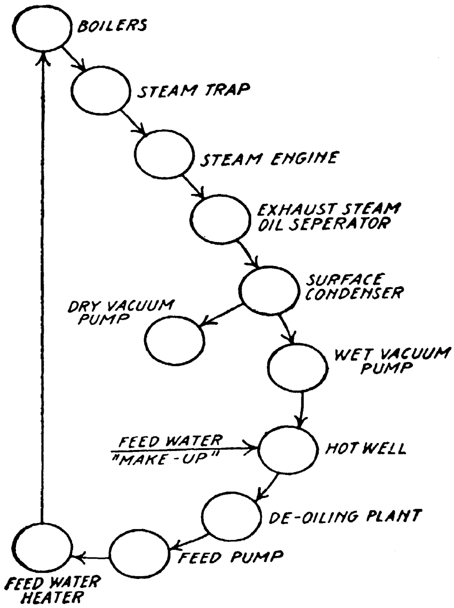
Marine Engines



Straight mineral, dark, or filtered oils must be used, but when an exhaust-steam oil separator is fitted, filtered oils lightly compounded are recommended and will give efficient lubrication; they *can* and *must* be used very sparingly.

DIAGRAM 5

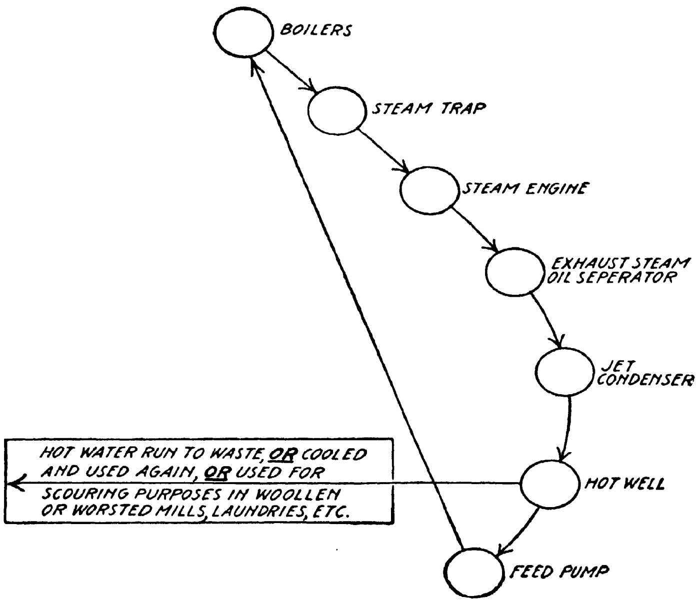
LARGE SURFACE-CONDENSING ENGINES IN LAND POWER PLANTS



The oil may be chosen entirely with a view to suiting the engine requirements, as every trace is eliminated from the feed water in the deoiling plant

DIAGRAM 6

LARGE OR SMALL JET-CONDENSING ENGINES



When an exhaust-steam oil separator is fitted, the oil may be chose entirely with a view to suiting the engine requirements; when no oil separato is fitted, and when the hot-condenser water is used and comes in contac with textile fabrics, heavily compounded oils must not be used.

TESTING CYLINDER OIL

The oil should be tested for a period of at least 3 months in case the first few days' working has been satisfactory. It takes time for a good cylinder oil to produce a good working skin on the internal wearing surfaces; in fact, it takes much longer than for an unsuitable cylinder oil to destroy the good surface produced by a suitable oil. After a few days, the consumption of oil should be gradually decreased, and the minimum feed determined by which smooth and satisfactory running can be accomplished. At the end of 3 months' working on the reduced feed the cylinders should be opened up for inspection and should present a surface of rather dull appearance, coated with a film of oil.

The same remarks will apply to the appearance of valve rods, piston rods, valves, and valve faces. Whenever a change of cylinder oil is made, irregularities may be experienced during the earlier period of its working, owing to the new oil's altering the wearing surfaces. Where unsuitable oils have been in use, and various deposits have accumulated behind the piston rings and in the glands, cylinder oil of a good grade will clean the surfaces. In such cases dirt may be carried to the piston rod, and the new oil generally gets the blame.

PHYSICAL AND CHEMICAL TESTS

Before giving specific recommendations for different types of steam engines, it may be well to examine briefly the physical and chemical tests most often referred to when judging the merits of cylinder oils.

These are specific gravity, viscosity, flash point, percentage and nature of compound, color, cold test, and loss by evaporation.

Specific Gravity.—The lower the specific gravity for oils of similar viscosity the purer the oil. A highly filtered cylinder oil will be lower in specific gravity than one less purified. It must be kept in mind that these statements are true only because practically all steam-cylinder oils are produced from paraffin-base crudes, which are rather similar in nature.

Viscosity.—The viscosity taken at 212°F. is always useful. It has been often referred to in the preceding pages in connection with "influencing conditions."

The admixture of tallow oil reduces the viscosity but increases the lubricating power of the oil—its oiliness. Filtered cylinder oils have lower viscosity than dark cylinder oils but greater friction-reducing powers. In comparing viscosities of different oils, one must therefore keep in mind whether they are compounded or more or less filtered.

Flash Point.—Although it is true that good cylinder oils for use with superheated steam do possess a fairly high flash point, yet it is by no means certain that a cylinder oil having a high flash point is suitable for work with superheated steam. The flash point is determined in the laboratory under atmospheric conditions. If the cylinder oil were to be tested under the high pressure carried in the steam pipe, the flash point would undoubtedly be shown to be considerably higher, just as the boiling point of water, which at atmospheric pressure is 212°F., increases with any pressure above that of the atmosphere; (*e.g.*, at 150 lb. per square inch the boiling point of water is 366°F.). This will explain why it is frequently possible to use a cylinder oil successfully for lubrication under superheated steam conditions where the temperature of the steam is even a *good deal higher than the flash point of the oil, measured under atmospheric conditions.*

Besides, there is practically no air present in the steam, and therefore no danger of the oil's flashing anywhere. The temperature of the piston or valve rods, which are the only hot frictional parts passing out into the atmosphere, is always considerably lower than the maximum steam temperature, so that the flash point of the oil is never reached; and even if it were reached, nothing much would happen, there being no chance of an explosive mixture's being formed of oil vapor and air, such as may be the case in air compressors.

Compounded Oils.—For most conditions, experience has proved that cylinder oils compounded with the proper kind and amount of fixed oil are more suitable than those which are straight mineral. It is more particularly where steam engines are working with wet steam that the advantage of using compounded oils becomes apparent. Great care must be exercised in selecting the proper kind of fixed oil, as unsuitable fixed oils under the action of steam at high pressure and temperature decompose and develop acids and gummy residues which corrode the internal wearing

surfaces and produce sticky, pasty deposits which unduly increase friction. Compounding mineral cylinder oils with the right proportion (from 4 to 15 per cent) and quality of fixed oil, preferably acidless tallow oil, usually adds to its lubricating value, and better results will be secured than if the cylinder oil is used without the admixture of fixed oil.

Color.—The more highly filtered a cylinder oil is the lighter will it be in color, so that light color (low Lovibond-color number) usually signifies a high degree of purity.

Cold Test.—It is desirable that a cylinder oil keep fairly fluid at ordinary engine-room temperatures, especially when used through hydrostatic lubricators, with which difficulty is always experienced in feeding viscous cylinder oils at a regular rate of feed. When good mechanically operated lubricators are employed, the cold test of the cylinder oil is of less importance.

Loss by Evaporation.—Such laboratory tests as determine the percentage of evaporation when heating a sample of cylinder oil to a certain temperature for a certain time are of very little value in determining lasting properties of a cylinder oil, as these tests are carried out under atmospheric pressure and under conditions greatly different from those met with in actual work.

It will be understood from the foregoing that the author considers the following tests of great importance:

Specific gravity and color—as indicating degree of purity.

Viscosity—to suit conditions of temperature and pressure.

Percentage and nature of compound—to suit wet-steam condition and increase oiliness.

Cold test (equivalent to viscosity at low temperatures)—to ensure proper feeding of the oil through the lubricators.

USE OF TALLOW MIXTURES AND SEMISOLID GREASES AS CYLINDER LUBRICANTS

Acidless tallow oil and not *tallow* is generally used for compounding cylinder oils, because tallow is often acid or rancid and therefore inferior to acidless tallow oil. Tallow and black lead used to be a favorite cylinder lubricant at sea, when steam pressures were low; but with the advent of higher steam pressures such mixtures have almost disappeared. Yet it is not infrequent to find engine drivers of both stationary and locomotive engines in the habit of using tallow indiscriminately, particularly under

wet-steam conditions; it keeps the engine quiet and makes the cylinder oil last longer. The acidity produced by decomposition of the tallow (into fatty acid and glycerin) will, however, in time act most destructively on all cast-iron surfaces. A symptom often exhibited is that the acid "perforates" the skin on the piston rods; the rod then becomes pitted and wears badly. It also causes, inside the valve chests and cylinders, deposits composed chiefly of iron soaps and may soon cause sufficient corrosion and pitting to ruin the surfaces after a comparatively short life.

In locomotives a portion of the deposits reaches the smoke-box exhaust nozzle and cakes, owing to the great heat, closing the nozzle and causing a labored exhaust until cleared away.

Cast iron long exposed to the action of fatty acids from tallow becomes so crumbly that it can be cut with a knife like cheese. The metal is porous and filled with iron soaps, etc., which explains why it is so exceedingly difficult to introduce an oil, largely mineral in character, where tallow (or, for that matter, any fixed oil, such as rape oil—Colza—occasionally favored by engine drivers for troublesome engines) or cylinder oils containing a large percentage, say 20 to 25 per cent or more, of tallow, tallow oil, or other fixed oil has been in use for a long period.

The only way is to introduce the oil *very gradually* mixed with the old lubricant over a period of *at least* 3 *months*, gradually increasing the percentage so as to give the acid products of decomposition time to loosen, dissolve, and get cleared away through the exhaust. If the oil is introduced too quickly, it will dissolve the deposits too rapidly, with the result that excessive scoring and wear inevitably take place, and a return to the old lubricant becomes necessary if the engine is not to suffer more serious damage.

In America, semisolid greases, containing more or less tallow, are not infrequently used as cylinder lubricants. They are more difficult to apply economically than a proper grade of cylinder oil and cannot possibly give better lubrication, as they either contain a percentage of nonlubricating material or, if they are rich in tallow and such like, give rise to troubles with corrosion of surfaces or with the feed water (too much compound). Weight for weight cylinder oil of the correct grade is always preferable, and besides it will be found that if the price per pound is compared with that of semisolid grease, the latter is always dearer.

The use of such lubricants cannot therefore be recommended from any point of view, except perhaps that of the manufacturer.

LUBRICATION CHART

The lubrication chart shown on page 409 gives specific cylinder-oil recommendations for all types of steam engines. Before describing how it is to be used, it will be necessary to describe what the various grades of cylinder oil represent.

Cylinder oils of four viscosity ranges—Nos. 1, 2, 3, and 4—have been found adequate for the lubrication requirements of all types and sizes of steam engines. These viscosity ranges are shown in the following table, also the approximate specific

VISCOSITY RANGE, ETC., OF CYLINDER OILS

Grade of cylinder oil	Viscosity number*	Viscosity, centipoises at 100°C.	Specific gravity		Open flash point, °F.		Cold test, °F.	
			Filtered	Dark	Filtered	Dark	Filtered	Dark
No. 1 filtered	11 to 13	14 to 18	0.885	.....	500	...	40 to 50	
No. 2 dark, No. 2 filtered	14	26	0.887	0.900	525	520	50 to 60	40 to 50
No. 3 dark, No. 3 filtered	15	32	0.890	0.905	550	530	50 to 60	40 to 50
No. 4 dark	16	40	.....	0.910	...	580	....	50 to 60

* See table, p. 57.

gravities, flash points, and cold tests, corresponding to these viscosities, for both filtered and dark oils.

There is no demand for dark oils of the viscosity of No. 1 grade, and it is not possible commercially to manufacture filtered oils of the No. 4 grade viscosity, nor do the actual requirements call for such oils. Filtered oils of the No. 3 grade viscosity are superior to dark oils of the No. 4 grade viscosity as regards oiliness (which is more important than viscosity), but they are more expensive to manufacture. The various oils may also be straight mineral or more or less heavily compounded with acidless tallow oil.

A few dark cylinder oils are marketed having higher viscosities and flash points than the No. 4 grade. Such oils are unneces-

sarily viscous, waste power, and easily carbonize and form deposits.

In the table below are indicated 12 grades of cylinder oils, 6 filtered and 6 dark, representing the author's recommendations based on practical experience with such oils on a vast number of steam engines.

TWELVE GRADES OF CYLINDER OILS

Cylinder Oil	Designation Number
No. 1 filtered, heavily compounded (10 per cent)	1 F.H.C.
No. 1 filtered, lightly compounded (4 per cent)	1 F.L.C.
No. 2 filtered, medium compounded (6 per cent)	2 F.M.C.
No. 3 filtered, medium compounded (6 per cent)	3 F.M.C.
No. 2 dark, medium compounded (6 per cent)	2 D.M.C.
No. 3 dark, medium compounded (6 per cent)	3 D.M.C.
No. 3 dark, heavily compounded (10 per cent)	3 D.H.C.
No. 4 dark, medium compounded (6 per cent)	4 D.M.C.
No. 2 filtered, straight mineral	2 F.S.M.
No. 2 dark, straight mineral	2 D.S.M.
No. 3 filtered, straight mineral	3 F.S.M.
No. 3 dark, straight mineral	3 D.S.M.

The 12 grades in the foregoing table will be found in the first column of the lubrication chart on page 409. The other vertical columns refer to the conditions influencing the choice of cylinder oil. The black squares in each column indicate the condition for which the cylinder oil (shown at the left extreme of the same horizontal line) is not suitable.

In order to find an oil suitable for a certain set of conditions, take a piece of paper and place it with its upper edge along the top line; make a pencil mark on the edge of the paper corresponding to each set of conditions and opposite the condition found in the steam engine in question. It is important that a mark be made corresponding to all seven groups of conditions in order that the recommendation made by the table may be correct. Having marked the paper at seven places, move it down to the first horizontal line; if none of the seven marks clashes with (corresponds with) any of the black squares on this line, Cylinder Oil No. 1 F.H.C. (No. 1 filtered, heavily compounded) is the correct grade of oil to use. If one or more of the black squares clashes

Lubrication Chart
For Steam Cylinders and Valves

	Size of Cylinders		Horizontal or Vertical Construction		Tailrod		Steam Pressure lbs./□"			Steam Temperatures Degrees Fahrenheit			Condition of Steam		Exhaust Steam Condition		
	Below 16"	Above 16"	Hori-zontal	Ver-tical	With	With-out	Below 100	Between 100& 140	Above 140	Below 400	Between 400& 525	Above 525	Wet	Dry	Non-Condens'g or Jet Condens'g	Surface Condens'g good means for Extracting Oil	Oil Elimination Particularly Important
1FHC		■						■	■			■		■		■	■
1FHC			■									■		■		■	■
1FHC			■			■					■	■		■		■	■
1FHC			Also Recommended for Large Low Pressure Cylinders with Wet Steam														
1FLC						■					■	■	■				■
1FLC						■		■	■			■	■				■
1FLC			■						■			■	■				■
2FMC			■				■					■					■
2FMC				■			■					■					■
2FMC		■	■				■			■	■						■
3FMC	■		■				■			■							■
3FMC	■			■		■	■			■							■
3FMC	■						■	■			■	■					■
2DMC									■		■	■				■	■
3DMC							■					■	■			■	■
3DHC	■						■					■		■		■	■
4DMC	■						■	■				■				■	■
2FSM or 2DSM									■			■			■		
3FSM or 3DSM	■						■								■		

Note 1.—For light-load conditions choose an oil slightly lower in viscosity and/or more heavily compounded than the one indicated by the chart.

Note 2.—With impure steam (boiler's priming, etc.) a filtered oil should preferably be used, and with saturated steam preferably compounded.

Note 3.—When the chart recommends more than one grade, the one lowest in viscosity should preferably be chosen; when a dark as well as a filtered oil is recommended, as will often be the case, the former, unless there are special conditions (Note 2), may be preferred, as it is (or ought to be) lower in price.

Note 4.—A straight mineral oil can always be used in place of the compounded oil recommended by the chart, but it means an increased oil consumption as compared with a medium-compounded oil of 50 to 100 per cent; the use of a straight mineral oil in place of a slightly compounded oil or the latter in place of a heavily compounded oil means an increase in oil consumption of 30 to 50 per cent.

Note 5.—From 10 to 15 per cent of compound may be required in case of (*a*) very wet steam in large engines, low-pressure cylinders in particular; (*b*) heavily loaded Corliss valves or unbalanced slide valves; (*c*) very dirty steam, particularly saturated steam.

Note 6.—No. 2 F.S.M. and 3 F.S.M. will separate more easily from the exhaust steam and feed water than No. 2 D.S.M., and 3 D.S.M. and will give cleaner and better lubrication, particularly under conditions of superheated steam and/or impure steam.

with the pencil marks, move the paper down to the next horizontal line. If there are still obstacles in the way (black squares) move to the third line and so on until a line is found where there are no obstacles opposite the pencil marks. The correct oil will then be shown in column 1 of that particular horizontal line. Do not go from line 1 to line 5, because the first four lines all refer to No. 1 F.H.C.; they represent different sets of conditions and no lines must be missed.

LOCOMOTIVES

Cylinders and Valves

From a lubrication point of view there are two main groups of locomotives, *viz.*, railway locomotives, employed in more or less regular service on railways; and works locomotives, such as are employed in steelworks, mines, quarries, and shunting locomotives.

Works Locomotives.—It is often painful to see the crude way in which lubrication is provided in most works locomotives. Many small locomotives are only fitted with tallow cups, and at best some kind of hydrostatic lubricator—as a rule, the cheapest possible—is installed.

With tallow cups, lubrication is always poor, whether the oil allowance is great or small. With hydrostatic lubricators there is always waste of oil, as they keep on feeding, quite independent of the actual requirements. The drivers are not so careful as railway-engine drivers and do not, as a rule, trouble to shut off the lubricator every time that the locomotive stops for a little while. Mechanically operated lubricators, operated from one of the valve spindles, similar to stationary-engine practice, will save a great deal of oil on all such locomotives and provide more uniform lubrication than will hydrostatic lubricators.

It is necessary to fix the mechanical lubricator with heavy brackets to the engine frame and to take every precaution that vibrations from the engines are felt by the lubricator as little as possible. The oil should preferably be introduced by means of an atomizer (see page 361) into the steam pipe in the smoke box, before it branches off to each cylinder.

When the oil is thoroughly atomized, the steam lubricates valves, cylinders, and piston rods, so that there is no need for

extra lubrication of the rods. But where hydrostatic lubricators or tallow cups are employed, it is necessary to have a swab or mop for the rod glands. Such swabs are made of worsted or cotton (lamp wicks), plaited and formed into a ring, placed round the rod and held in position by the gland nuts; they are preferably enclosed in a box to protect them from dust and grit.

Railway Locomotives.—Coming now to the other and more important group of locomotives—those employed in regular railway service, whether passenger or freight—we find that there is one condition that vitally affects the lubrication question, *viz.*, that when a train passes a down-gradient portion of the line, the steam is practically shut off; *i.e.*, the engine is what is termed "drifting" with a closed throttle. If the oil under these conditions were introduced into the steam pipe, there would be no steam to carry it into the valves and cylinders; and if the down gradient were a long one, the rubbing surfaces would soon be devoid of lubrication.

During periods of drifting, another complication occurs; the valves and pistons act like pumps and may create a vacuum ranging from 3 to 9 lb. on the exhaust side which sucks ashes and soot into the cylinders from the smoke box. These impurities adhere to the cylinder oil and may form very objectionable crusty deposits in the valves, passages, and cylinders. To overcome this difficulty, good practice requires either that the driver shall very slightly open the regulator when the engine is drifting or that a by-pass valve (snifting valve, antivacuum valve) be provided, which automatically admits sufficient *steam* to the cylinders so as to kill the vacuum and prevent the entrance of soot and ashes. Some snifting valves are designed to admit *air* instead of steam or *air and steam.* This practice is permissible for saturated steam, but with superheated steam the internal temperatures are so high that the air immediately oxidizes the oil and causes the formation of sticky, carbonaceous deposits.

It will now be realized that the condition of "drifting" necessitates the oil's being introduced straight into the valves and cylinders. With saturated steam an oil feed to the cylinder is seldom required, but with superheated steam the cylinder feed cannot be dispensed with.

Speaking generally, 75 per cent of the oil is preferably introduced into the valve chest, and 25 per cent into the cylinders.

As to the method of introducing the oil, there can be no question of the superiority of the atomization system over all others, and for superheated steam conditions in particular, as will be explained presently.

Lubricators

Both hydrostatic displacement lubricators and mechanically operated lubricators are employed and there have been great controversies of opinion as to their respective merits.

Hydrostatic Lubricators.—These lubricators are fitted in the cab, as shown in Fig. 149. Steam is admitted to the lubricator,

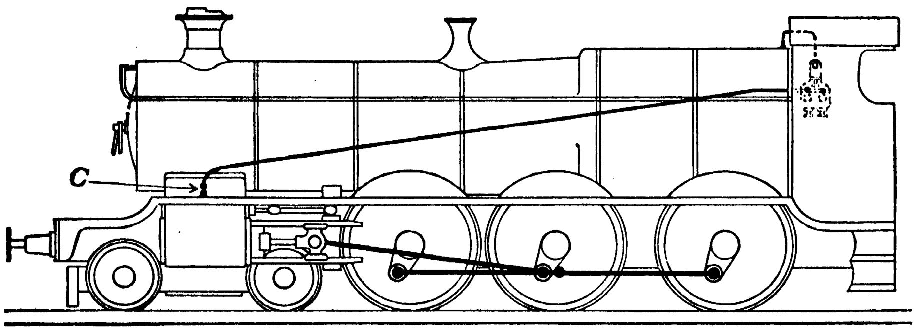


Fig. 149.—Hydrostatic locomotive lubricator.

condensing in the upper part it; by gravity displacement the oil is forced up through sight feeds, and through long feed pipes it finally reaches the valve chests and cylinders. The best hydrostatic lubricators admit saturated steam to the feed pipes. The steam keeps the pipes hot and more or less emulsifies the oil, so that it is readily atomized in passing through the choke plug *C*, always fitted before the oil enters the engine. Figure 150 shows in detail such a choke plug; a valve (1) is kept constantly vibrating on its seat by the motion of the engine; the mixture of oil and saturated steam passes through fine channels and cross channels in the valve or between the valve and its seat; the churning action thoroughly atomizes the oil; in fact, what is produced is really oily steam—"Scotch fog"—which spreads quickly over the internal surfaces and forms the best means by which the oil can be distributed.

If the choke plugs were absent, the difference between the boiler pressure and the pressure in the valve chest or cylinder

would cause waste of steam through the oil feed pipes, particularly when drifting. The choke plugs are therefore required for the dual purpose of checking the steam flow and atomizing the oil.

When applied to locomotives employing *saturated steam*, two feeds, one for each valve chest, will suffice for most high-pressure engines; but the cylinders in large engines will occasionally be better lubricated if they are lubricated direct, so that a four-feed lubricator is required. An extra feed may be added for feeding the air-pump cylinder. This oil feed must not have steam admission; the oil drops through a sight feed and gravitates to the air cylinder.

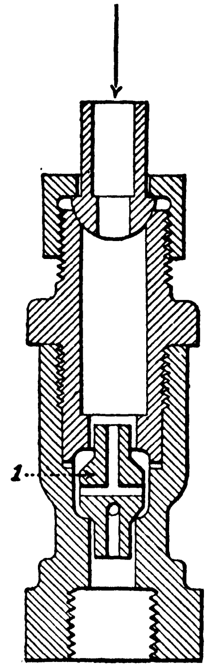


FIG. 150.—Choke plug *C* (Fig. 149).

For *superheated-steam* conditions, *hydrostatic lubricators* are used almost exclusively in the United States and Canada. Some British railways are also using them and getting good results.

Although the lubricators first fitted had a great number of feeds, it seems now to be an established fact that for all two-cylinder engines one feed into each valve chest (into the middle with inside steam admission or a divided feed into both ends with outside steam admission), one feed into each cylinder, one feed divided to the tail rods, and one feed for the air pump, making six feeds in all, will provide proper oil distribution. For four-cylinder engines more feeds are required, and it is advisable to fit two lubricators, one for either side.

In the United States the oil feeds on each side are often divided to serve both valve and cylinder, but in view of the uncertainty as to which path the oil will choose, it seems better practice to feed the valve and cylinder by separate feeds. If feeds are to be divided, it would be better to divide one for both valves or for both cylinders, as with this arrangement one may with better reason expect a fair distribution of the oil.

The division of feeds must, of course, be done *after* the oil has passed the choke plugs. As to British practice, at least one railway has divided the cylinder feed without any apparent ill effects, but the feeds to the valve chests have not, to the author's knowl-

edge, been divided. As the greatest amount of oil has to be fed to the valves, this practice appears to be sound and preferable to the American one of dividing the feeds, which certainly introduces an element of uncertainty.

Mechanically Operated Lubricators.—Mechanical lubricators have a container from which the oil pumps draw the oil; the container, therefore, is not under pressure and can easily and quickly be refilled with oil. Filling a hydrostatic lubricator with oil is more complicated, as the water first must be emptied out, and there are several valves to look after every time to ensure correct working of the lubricator when starting up again. Mechanical lubricators start feeding as soon as the engine starts and stop feeding with the engine, so that no oil is wasted while the engine is standing. Hydrostatic lubricators must have their oil feeds started about 10 min. before the running, and they keep on feeding while the engine is standing or running slowly.

Mechanical lubricators feed the oil according to the speed of the engine, whereas a hydrostatic lubricator will feed approximately the same amount of oil whether the engine goes fast or slow, whether on an uphill or a downhill gradient. When superheated steam was first introduced on the Continent, mechanical lubricators were thought necessary; the principle of atomization was not understood or appreciated, and as a result the great majority of locomotives in Europe, South Africa, India, and the East generally are fitted with mechanical lubricators without any attempt's being made to atomize the oil. Numerous troubles with excessive carbonization, heavy wear, and friction are recorded, too numerous to be disregarded.

What happens is that the oil is injected unatomized into the valves and cylinders; it is very viscous and spreads only with difficulty; it is exposed to high temperature, to the oxidizing effect of hot smoke-box gases and boiler impurities, and to contamination from soot and ashes. As a result, particularly if the oil consumption is liberal, very tenacious sticky or hard carbonaceous deposits are formed. The rubbing surfaces become poorly lubricated, and heavy friction and wear take place. Frequent cleaning of valves and cylinders and keeping the oil consumption as low as possible will assist in preventing trouble, but even with the best possible attention to these points it is difficult to ensure perfect lubrication.

Of course, if suitable antivacuum valves are fitted, if the boiler water is of good quality, and priming only slight or absent, it is possible to get good results with mechanical lubricators. But results in practice generally fall short of perfection, and it is under more or less unfavorable conditions that feeding the oil unatomized is almost sure to give trouble. The fault is not with the mechanical lubricators themselves. Stationary practice has long since proved that they are superior to and more economical than

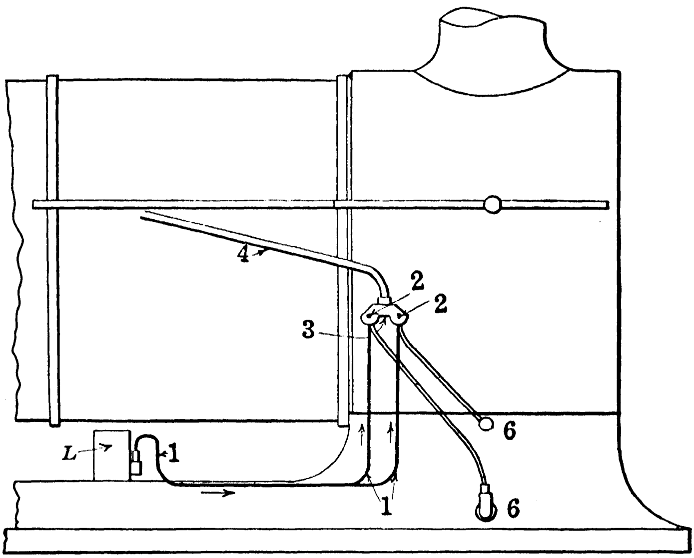


FIG. 151.—Thomsen's atomizer arrangement.

hydrostatic lubricators; the cause of most carbonization troubles is simply that the *oil is not atomized.*

The good results obtained with hydrostatic lubricators under superheated steam conditions have proved that if the oil is introduced as oil fog, saturated steam being the carrying medium, it has the effect of keeping the rubbing surfaces free from deposit. Whatever impurities may be drawn into the engine during periods of drifting are prevented from caking and are expelled through the exhaust when steam is again admitted.

Experience has proved that perfect atomization is imperative, if carbon deposits are to be avoided with superheated steam.

The author believes that he was the first to suggest the combination of mechanical lubricators with atomizing boxes (in a paper read before the Institution of Locomotive Engineers, London, on Mar. 25, 1915). Figure 151 shows the author's

design, which has proved efficient in overcoming carbonization troubles. The feed pipes (1) from the mechanical lubricator *L* discharge oil through check valves (2) into the atomizer box (3), shown in detail in Fig. 152. Saturated steam is supplied through an auxiliary pipe (4) and causes the oil to be preliminarily atomized through the saw slits of the atomizer (5); the mixture of oil and saturated steam is finally atomized in passing through the choke plug (6).

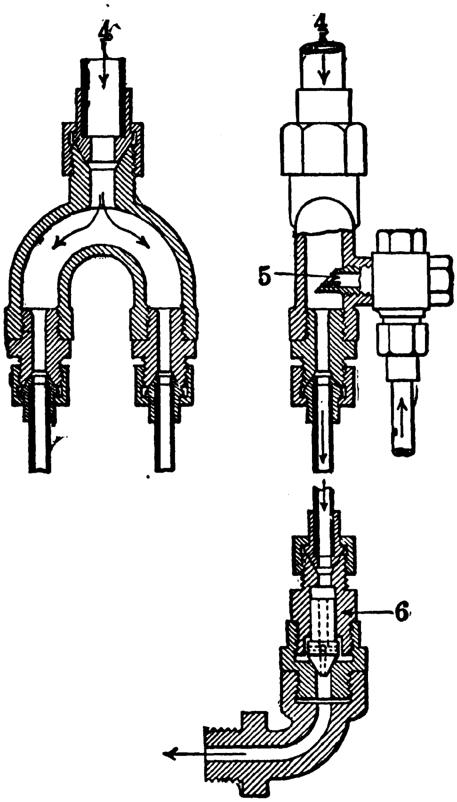


FIG. 152.—Atomizer box.

It will thus be seen that the steam has an unobstructed flow through the atomizer box and that each feed gets its fair share of the steam supply. The number of oil feeds required is exactly the same as with a hydrostatic lubricator. Without the atomizer box, piston valves require two oil feeds, one for each end; but with the atomizer box, one feed for the center or one feed divided for each end, as the case may be, will suffice.

The combination of a mechanical lubricator with a suitable atomizer box, in the author's opinion, offers the chief advantages of the best types of hydrostatic lubricators with all the advantages of mechanical lubricators. Only those oil feeds requiring to be atomized are carried to the atomizer box. Oil feeds for feeding oil under pressure to the axle boxes may be taken from the lubricator, and, if need be, the lubricator can be made with two compartments, so that a separate oil—axle oil—can be used for the bearings, and cylinder oil for the valves and cylinders. A hydrostatic lubricator can, of course, not be arranged to feed pressure oil to the axle boxes.

Mechanical lubricators are fitted either in the cab near the driver or on the framing near the main points of lubrication.

Motion may be taken from the back axle or from one of the rods, as shown in Figs. 153 and 154.

The check valves should be designed to avoid steam's leaking back, and the vibration calls for special care; ordinary miter-seated valves are not satisfactory. Figure 155 shows one designed by the author, which has proved efficient under trying conditions. It will be seen that the spring operating the valve is on the oil side and not exposed to the steam; the valve has to be lifted until the cylindrical part is above the seat before the oil will be discharged.

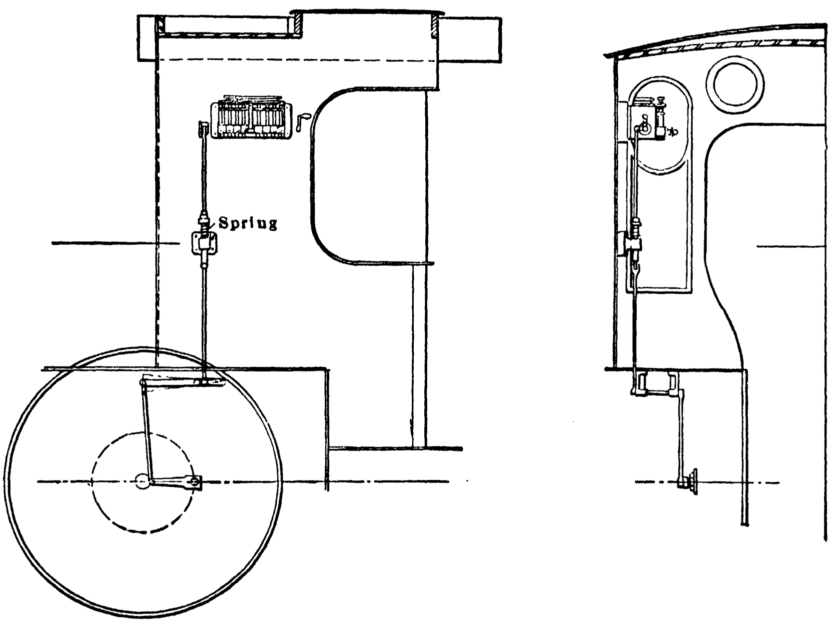


FIG. 153.—Back-axle motion for mechanical lubricator.

When oil is not pumped through the valve, the cylindrical portion below the head forms an effective seal against the entrance of steam into the oil pipe. By unscrewing the cleaning and testing plug, a straight passage is disclosed for cleaning the oil passage leading into the valve or cylinder. This plug is screwed back when testing the oil feeds. There are three oil holes below the head, through which the oil will exude.

A similar type of check valve should also be used in the oil pipes from a mechanical lubricator to the axle boxes. The check valves should be fitted in accessible positions and as near the axle boxes as possible.

Mechanical lubricators for locomotives, particularly when placed on the framing, should be provided with a steam-heating

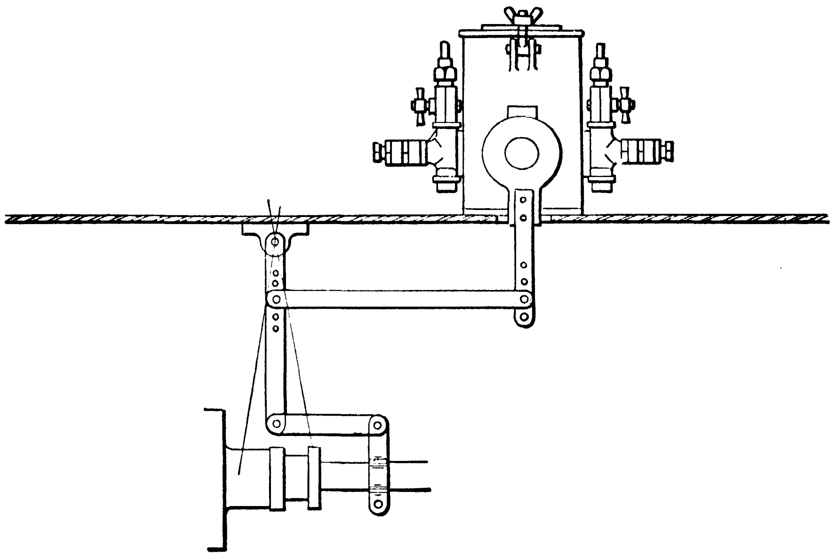


FIG. 154.—Rod motion for mechanical lubricator.

arrangement, as, if the cylinder oil becomes very thick or congeals, the oil feeds will be considerably reduced or stop altogether.

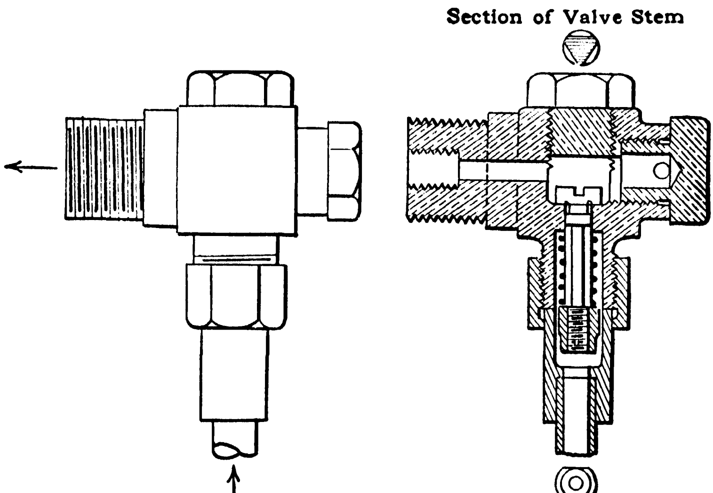


FIG. 155.—Locomotive check valve.

As to placing the mechanical lubricators, they are undoubtedly best placed in the cab, where the lubricator is under the eye of the driver and stoker, and where each feed to each part of the engine

can be properly controlled and regulated. This also makes it possible to give extra oil when required by having a flushing handle on the lubricator, by means of which all the oil feeds can be flushed. Where mechanical lubricators are placed on the frame, the driver cannot control and watch the feeds from the cab. If one of the feeds gets out of order, he will not be able to recognize this before the engine gives audible notice by grunting or otherwise, and then a great deal of damage may already have been done.

It is felt by some engineers that the drivers should not be allowed to adjust the feeds when once set by an expert in the running shed or during a couple of days' service on the road. The lubricators can, of course, be arranged with locked adjustments, but the drivers should in any case be enabled to watch the sight-feed glasses and *test* the oil feeds; they should also have access to the suction valves and to the flushing arrangement.

The combination of a mechanically operated lubricator with an atomizer box appears to be the best solution for lubrication of all locomotives in those outlying countries which employ native drivers, as it is desirable that the lubrication be as automatic and foolproof as possible, and the control largely taken out of the driver's hands.

For those countries in Europe and America where intelligent drivers are available, the hydrostatic lubricator, with intelligent care, is capable of giving good service, and it will probably continue to be much used for saturated-steam conditions. As, however, the consumption of oil with mechanical lubricators can be automatically kept nearer the actual requirements than with the hydrostatic lubricator, which requires frequent and intelligent adjustment by the driver, it would not be surprising to find the mechanical lubricator gaining in favor for saturated-steam service. For superheated steam conditions the author thinks that the development will certainly be in favor of the mechanical lubricator, due attention being paid to the atomization principle.

LOCOMOTIVE-CYLINDER OILS

Most locomotives operate with rather high steam pressures, ranging from 140 to 225 lb. per square inch or even higher.

Most works locomotives have slide valves, but many railway locomotives have piston valves. Slide valves have been used with a moderate degree of superheat; but for high superheat,

piston valves are universally adopted, and in most cases also tail rods. Piston rings and pistons wear much better when tail rods are fitted. It is not considered advisable to exceed a steam temperature of 650°F.

In the early days much trouble was caused by the growth of cast iron when exposed to superheat temperatures. For a long time it was thought that the cylinder oil was to blame for the excessive wear and the many cracked cylinders, etc., but eventually the swelling was found due to the combined carbon in the iron. A more suitable cast iron was discovered and solved the difficulty, and many railways found that good-quality filtered cylinder oils, which they had previously used with saturated steam, served quite well also with superheated steam.

Owing to the wet-steam conditions often met with in locomotives or to bad water or to the necessity of keeping an extra-high water level before negotiating a long uphill gradient, experience had already taught some railways that well-filtered green cylinder oils, compounded with from 6 to 10 per cent of acidless tallow oil, gave cleaner and better lubrication on a much reduced feed as compared with dark cylinder oils, whether straight mineral or compounded. The majority of railways, however, still use dark cylinder oils for all conditions, because they are lower in price than filtered cylinder oils.

Experience has proved that locomotive-cylinder oils should certainly be compounded. If the conditions as regards priming, drawing in soot, etc., are not too trying, dark compounded cylinder oils will give a reasonable amount of satisfaction; but under unfavorable conditions, compounded filtered cylinder oils should always be preferred, as they maintain the valves and cylinders in a much cleaner condition, which is worth a great deal from both a frictional and a wear-and-tear point of view.

For works locomotives fitted with poor lubricators, it is usually a waste of money to use filtered cylinder oils, and dark compounded oils are recommended. The use of tallow should be discouraged, but it will often be found that collieries and steelworks buy low-priced, straight mineral, dark cylinder oils; that the locomotives use the oil extravagantly; and yet that the lubrication is so poor that engine drivers get tallow (or, if they are not allowed to have it, get it all the same) to keep their engines quiet.

The bad effects of using tallow are mentioned on page 406. Locomotive-cylinder oils should obviously have good setting points, so that low-setting-point filtered cylinder oils should be recommended which will flow freely in the lubricators and give a uniform feed. Compounded filtered cylinder oils will also lubricate the air-pump cylinder satisfactorily, if fed sparingly, and very little oil vapor will be carried over with the compressed air into the air-brake system.

The *consumption of cylinder oil* required for full lubrication varies from ¼ to 1¼ pt. per 100 miles, according to the size of the locomotive. The oil consumption for the air pump varies between ¼ and ½ pt. per 100 miles and should be kept as low as possible.

Where an engine has a long continuous run to make, it is good policy for one shift of driver and fireman to hand it over to the next shift with the lubricator *filled with oil;* in this way, control of the various drivers' oil consumption is made quite easy.

LUBRICATION CHART FOR LOCOMOTIVES

Locomotives*	Cylinder Oil†
Works:	
Small	2 D.M.C.
Larger	3 D.M.C.
Railway:	
Saturated steam	3 F.M.C. or 3 D.M.C.
Superheated steam	3 F.M.C.

* For very wet steam, the same grades are recommended but with 10 per cent of compound.

† For information as to the grades of cylinder oils recommended see p. 408.

CHAPTER XXVI

BLOWING ENGINES AND AIR COMPRESSORS

Compressed Air.—Compressed air is used for a variety of purposes—for supplying blowing air to blast furnaces and Bessemer converters; for operating pneumatic tools, such as pneumatic hammers, drills, riveters, etc., as used in engineering works, boiler shops, foundries, forge shops, shipyards, docks, and bridge building; for rock drills used in mines and quarries; for operating underground machinery in collieries; and for sinking tunnels and shafts. It is also used for operating different types of lifting and hoisting gear, railway-car brakes, electro-pneumatic signals, and pneumatic-tube carrying service; for pumping water; for lifting and conveying liquids in breweries, distilleries, and chemical works; for aerating oils in large edible-oil refineries; and for spraying paint.

Compressed air is employed for starting gas engines and other internal-combustion engines; also for injecting and atomizing fuel oil under furnaces or in Diesel engines. Very highly compressed air is used for producing oxygen and liquid air.

TYPES OF BLOWING ENGINES AND AIR COMPRESSORS

Blowing engines supply large volumes of air at low pressure. Blast furnaces require air at 10 to 25 lb. per square inch; Bessemer converters require it at 20 to 30 lb. per square inch.

Blowing engines operate at low speeds—from 30 to 70 r.p.m.—and are single-stage machines; they are operated by either steam or gas engines; the gas engines are nearly always horizontal two-stroke cycle engines, driving the air cylinder tandem fashion. When driving the blowing engines by steam engines, the steam and air cylinders are also usually placed in tandem. In horizontal blowing engines the piston nearly always has a tail rod. When the tail-rod support is not present, the whole of the weight of the piston is sliding on the bottom of the cylinder, demanding the use of heavy-bodied oils.

Air compressors compress air to high pressures. Colliery air compressors compress large volumes of air to a pressure of 60 to 80 lb. per square inch; they are sometimes single-stage compressors, but more frequently they are two-stage.

The majority of compressors used for a variety of purposes, as enumerated above, compress air to a pressure of from 80 to 120 lb. per square inch. Small compressors operating at a high speed are frequently single-stage machines up to a delivery pressure of 120 lb. per square inch. Large compressors are nearly always two-stage machines when the air pressure exceeds 70 lb. per square inch. Small- or medium-size compressors used in connection with semi-Diesel oil engines compress air to about 400 to 450 lb. per square inch and are two-stage machines.

CLASSIFICATION OF AIR COMPRESSORS AND BLOWING ENGINES

Blowing engines and air compressors	Air pressure, pounds per square inch	R.p.m.	Single or double acting
Blowing engines:			
Blast furnace	10 to 25	30 to 70	Double acting
Bessemer converters	20 to 30		
Air compressors (exclusive of Diesel-engine compressors)			
Small vertical compressors:			
Single stage	Up to 120	300 to 500	Single acting
Two stage	Up to 450		
Small horizontal compressors:			
Single stage	Up to 120	150 to 250	Double acting
Two stage	Up to 450		
Large vertical compressors:			
Single stage	Up to 70	60 to 360	Usually single acting
Two stage	Up to 150		
Large horizontal compressors:			
Single stage	Up to 70	40 to 150	Double acting
Two stage	Up to 150		

Air compressors used in connection with Diesel engines compress air to a pressure of about 1,000 lb. per square inch (see "Diesel Engines," page 564).

Air compressors when used in connection with the production of oxygen compress air to a pressure of 2,000 lb. per square inch and are usually four-stage machines. The types used for

charging torpedoes compress air to 3,000 lb. per square inch and are usually four- or five-stage machines.

Horizontal air compressors are usually steam driven with steam and air cylinders in tandem. Vertical air compressors may be driven by steam, by an electric motor, or by belt from a transmission shaft.

Blowing engines and air compressors may be classified as shown in the table on page 423. A compressor, whether it be a single- or a two-stage machine, is classified as small or large, according to whether the *volume of free air entering* the machine is less or more than 1,000 cu. ft. per minute.

AIR COOLING AND FILTRATION

Cooling.—As blowing engines compress the air only to low pressure, the amount of heat produced is not very great, so that blowing-engine cylinders are practically never water cooled. In air compressors which compress the air to higher pressures and which operate at much higher speeds, the heat of compression is great, particularly around the outlet valves, through which the hot compressed air is discharged.

Cooling of the air-compressor cylinder therefore becomes necessary, and, under severe conditions, attempts are frequently made to cool also the parts in close proximity to the outlet valves. Without adequate cooling, the temperature would rise, causing unequal expansion and distortion of the compressor cylinder, valves, and valve seats. The lubricating-oil film between the piston rings and cylinder walls would be thinned out, losing its sealing power, and the compressed air would leak past the piston. The discharge valves would not keep airtight (distortion due to heat), resulting in wiredrawing and recompression of the air, charring of the lubricating oil, excessive carbonization, friction, and wear.

If air at a temperature of 60°F. is compressed in a one-stage compressor to 100 lb. per square inch, its temperature will theoretically increase to 485°F.; under actual working conditions it will, however, be lower, owing to the cooling effect of the cooling-water jacket.

When air is compressed at a temperature of 60°F. to 100 lb. pressure in a two-stage compressor, compressing the air to, say, 35 lb. pressure per square inch in the low-pressure cylinder and

cooling it in an intercooler, the temperature of the air leaving the high-pressure cylinder will be considerably lower—from 200 to 250°F.—only in rare cases going as high as 300°F. This example shows the value, as far as lubrication is concerned, of compressing air in several stages when the final air pressure required is high.

The effect of the lower temperature is also that it takes considerably less power to compress the air (20 per cent less in the case just mentioned), this forming another strong reason in favor of multiple-stage compressors.

The air is frequently cooled in an aftercooler when leaving the compressor. In cooling, it will deposit its surplus moisture

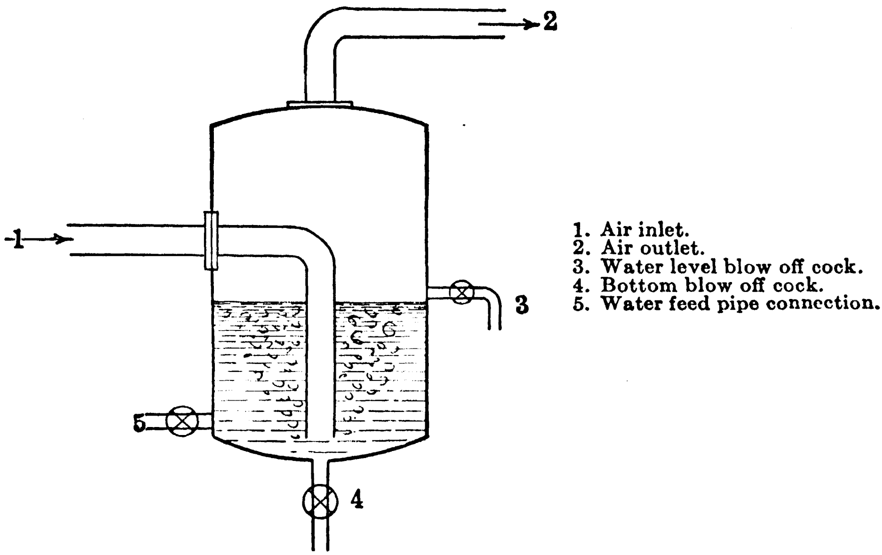


FIG. 156.—Air purifier.

and a large portion of the oil, which is thus prevented from reaching the receiver.

Occasionally, a separator partly filled with water is fitted in series with or in place of the aftercooler (Fig. 156). The water assists in extracting dust and excess water from the air. A feed pipe and blowoff cock are fitted, as indicated, so that the water can be changed under pressure. Accumulated oil can be blown out from time to time through a scum cock. This may also be connected to an automatic trap.

Filtration.—Where the air is charged with dust, a strainer or filter should be fitted. It may be made of screens of wire gauze and may contain cotton wool or fiber, in order to retain the

impurities. If the air is dirty, and impurities reach the compressor, the impurities will adhere and cling to the oil film, baking together into carbonaceous deposits. The intake air should therefore be taken from outside the compressor room and from as clean a place as possible. It may be freed from dust by passing through a container filled with 3-in. stones, coated with thick refuse oil and closed with grids to keep in the stones. The container and stones should be cleaned once or twice a year, and the stones recoated with oil.

METHODS OF LUBRICATION

Feeding Oil into Air Intake.—In small and medium-size air compressors, oil is occasionally introduced into the flow of air passing through the air-inlet pipe. The air atomizes and carries the oil in the form of a fine spray into the cylinder. The oil is cold, and the air is not a good carrying medium for oil, so that frequently this practice does not give the best results.

In horizontal air compressors or blowing engines, if the oil is introduced into the air intake, it will with difficulty reach the top portion of the piston, as it arrives there only by slowly wedging its way up around the sides. This practice is therefore uneconomical, as a large quantity of oil has to be fed in order to ensure its reaching the top of the piston.

In vertical air compressors the practice of feeding oil into the air-inlet pipe has a greater chance of distributing the oil than in horizontal air compressors, but it is also here rather wasteful and not conducive to the best results.

Feeding Oil Direct.—Generally speaking, it is better to feed the oil direct to the frictional surfaces, feeding it sparingly and uniformly. In horizontal blowing engine or air-compressor cylinders, the oil is introduced at the center of the cylinder, either at one point, at the top; or at three points, one at the top and two lower down. It will then gradually work its way around the piston and form a complete sealing and lubricating film.

In vertical cylinders, oil is introduced at two points, front and back, or at several points evenly spaced around the cylinder. Each oil inlet to the cylinder should preferably be fed by a separate oil pump, so that each feed can be controlled with certainty. If one oil pump supplies several oil inlets to the cylinder, the oil will take the path of least resistance and will not feed through those inlets which have become choked with dirt or deposit.

Splash from Crank Chamber.—In vertical enclosed high-speed air compressors where the external moving parts are enclosed in a crank chamber and lubricated by means of either the splash system of lubrication or the force-feed circulation system, the oil is either splashed or forced to all parts requiring lubrication, so that no separate oiling of the piston is required. On the contrary, the difficulty is usually to prevent too much oil from passing the piston rings and getting to the top of the piston, where, exposed to the high temperature and oxidizing effect of the air, it will in time bake into a carbonaceous deposit.

The presence of a large amount of oil in the air also produces a similar deposit on the discharge valve, frequently causing great trouble.

Valve Lubrication.—*Grid valves* have large sliding surfaces which must be lubricated direct, by introducing the oil at several points, sparingly and uniformly, the oil gradually finding its way all over the sliding surfaces.

Flap valves have hinges which must be oiled, sparingly and uniformly, the oil being introduced through feed pipes passing through the cylinder head.

Leather-disk valves need no lubrication, but the leathers must be kept flexible and in good order by occasional application of neat's-foot or lard oil.

Corliss valves (used only as suction valves) need lubrication, particularly at their ends, where the valves have their bearing surfaces; the oil must be introduced direct to these ends, sparingly and uniformly. The practice of fitting grease cups supplying grease to the valve ends is not to be recommended, partly because grease spreads only with difficulty over the rubbing surfaces, and partly because it bakes together with the impurities in the intake air into a pasty, sludgy deposit, causing excessive friction and wear; some of the grease will reach the valve chamber and even the cylinder, where it will bake together with impurities and cause an objectionable varnish-like deposit.

Poppet valves usually get sufficient lubrication from the oil in the air.

Plate or disk valves require no lubrication.

Bucket valves themselves require no lubrication, but their spindles must be sparingly lubricated.

Lubrication of external parts is by means of splash oiling or force-feed circulation in the case of all high-speed enclosed-type

air compressors; in open-type air compressors any of the many systems employed for bearing lubrication may be employed and do not call for any special comments.

With splash oiling it is very important that the correct oil level be maintained, so that an adjustable overflow should preferably be fitted to the crank chamber.

Owing to the high efficiency of the force-feed circulation oiling system and to the vertical construction, vertical air compressors may operate at much higher speeds than horizontal air compressors, as indicated in the table on page 423.

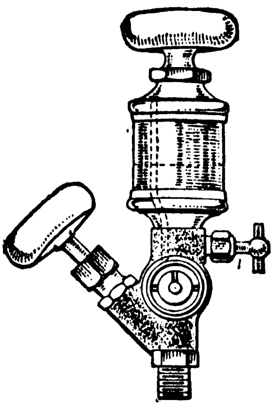


FIG. 157.

Care should be taken that the piston rings and oil scrapers on the lower part of the trunk pistons are pegged and in good order; they will then wear to a fit with the cylinder and keep oiltight and compression-tight.

In vertical enclosed-type air compressors employing the force-feed circulation oiling system, the oil pressure should not exceed 5 to 15 lb. With excessive oil pressure too much oil spray is formed, and too much oil is inclined to pass the pistons, particularly when the governor operates by throttling the intake air as the high vacuum created in the cylinders tends to draw the oil past the piston rings.

Splash guards fitted over the crank webs and pegging the piston rings will assist materially in reducing the oil consumption.

LUBRICATORS

Usually, sight-feed drop oilers or mechanically operated force-feed lubricators are employed.

Sight-feed drop oilers are subject to considerable variation in oil feed. If the containers are full, they will feed, say, 3 drops per minute; when they are nearly empty, they will feed, say, 1 drop per minute. They also vary with the temperature of the oil, the feed increasing when the oil gets warm and thin; in addition, when they are adjusted to feed a very small amount of oil, which is required in air-compressor practice, grit or dirt may easily choke the needle valve controlling the oil feed.

When a sight-feed drop oiler is to feed oil direct into the cylinder, it must be enclosed, so that it will feed notwithstanding

the varying back pressure (see Fig. 157). A pressure-equalizing pipe connects the sight-feed chamber with the space above the oil in the oil container.

The oil should preferably be fed by means of a reliable *mechanically operated lubricator*, having positive visible oil feeds and of such construction that it will feed the minimum quantity of oil with the greatest regularity and precision. The oil feeds, once adjusted, should remain absolutely constant, independent of the oil level in the container and independent of the viscosity of the oil.

OIL DEPOSITS AND EXPLOSIONS

All open-type compressors are so constructed that an oil specially chosen to suit the air-compressor requirements can be employed and applied quite independently of that used for the external moving parts. In enclosed-type air compressors the same oil must be used for air cylinders and bearings, and both requirements must be given consideration. The chief trouble in air-compressor lubrication is the formation of carbon deposits which may or may not bring about explosions or fires.

Deposits.—Deposits may form on the pistons, piston rings, and valves and in the discharge chambers, pipes, coolers, and receivers.

Deposit on the piston rings may fill up the grooves and make them inoperative, causing heavy friction and wear and air leakage past the piston.

Deposit on the discharge valves and valve seats prevents the valves from seating properly; the hot compressed air will leak back into the cylinder on the suction stroke; recompression will cause the temperature of the discharge air to increase above normal.

If a discharge valve sticks in a partly open position, the air is wiredrawn and recompressed continuously; the hot air heats the valve, and the temperature may easily rise to 700°F. or more, which is the spontaneous-ignition temperature of average-quality oil. The deposit now becomes incandescent, and accumulated oil will vaporize and burn or explode. Most explosions in colliery compressors appear to be caused by discharge valves' sticking.

Deposit on the suction valve causes leakage on the compression stroke, and wiredrawing of the air causes heating of the valve and seat.

Deposits in the discharge pipe restrict the opening; cases have been known where they have been almost choked, causing abnormally high pressure and temperature of the discharge air.

Deposits may develop due to impurities in the intake air, inefficient cooling, too warm intake air, too much oil, or unsuitable oil.

Impurities in Intake Air.—When air compressors operate in dusty surroundings, as in collieries and quarries, the dust frequently brings about deposits inside the compressor cylinders, valves, etc., unless the intake air is filtered.

In one colliery several explosions had occurred in one of their compressors; but when it was arranged to filter the intake air (which revealed how very dirty the air was), no further explosions took place.

In another colliery an electrically driven compressor was placed down a pit in a place where the coal trains passed by, with the result that the pistons and valves were constantly choking up with deposit, and heavy wear took place. A sample of deposit taken from the valves showed the following analysis:

	Per Cent
Moisture	Traces
Oil	26.0
Volatile matter (coal dust and oil carbon)	54.0
Fixed carbon and silica	0.9
Iron oxide (chiefly wear)	18.1
Balance—undetermined	1.1
	100.0

A filter was then installed, and the compressor kept very much cleaner.

Inefficient Cooling may be due to furring up of the water jackets; the result is that the oil is charred and bakes together with metallic wearings from the piston, piston rings, and cylinder.

Neglect on the part of the attendant in not turning on the cooling-water supply when starting the compressor has been responsible for such deposits and even for explosions.

Warm Intake Air.—The warmer the intake air the hotter will be the discharge air, the results being similar to those of inefficient cooling. A certain difference in temperature of the intake air means a much bigger difference in that of the discharge air, which emphasizes the desirability of having the intake air as cool as possible.

Too Much Oil.—Air compressors require very little oil for lubrication because the oil remains a long time once inside the compressor; there is no steam to wash it away as in steam engines, and there are no high temperatures to burn it away as in internal-combustion engines.

Air compressors *can rarely get little enough oil;* the excess oil remaining on the piston or valves often gets charred into a hard carbonaceous deposit.

Unsuitable Oil.—The character of the oil itself greatly influences the character and amount of carbon deposit formed.

Pale oils containing chiefly saturated hydrocarbons—naphthenes or paraffins—produce less oil carbon than such dark-colored oils which contain types of hydrocarbons easily decomposed by oxidation.

Distilled oils produce much less deposit than undistilled oils. Exposed to high temperatures they distill away almost completely, leaving comparatively little residue behind, whereas *undistilled oils* exposed to high temperatures distill only partly, leaving a spongy carbonaceous residue behind. Dark cylinder oils leave much more residue than filtered cylinder oils and ought never to be used for air-compressor service.

As regards fixed oil, it is obvious that semidrying or drying oils cannot be permitted as an ingredient in air-compressor oils, but the presence of a small percentage—say, 3 per cent—of non-drying animal oil is not detrimental to air-compressor lubrication; in fact, it has proved a distinct advantage in multiple-stage high-pressure air compressors where the air in the higher stages is wet (see "Diesel Compressors," page 564). For low- or moderate-pressure compressors, when the air is comparatively dry, the admixture of fixed oil is unnecessary.

Oils too heavy in viscosity are largely responsible for deposits; the dust and dirt in the air adhere to the sluggish oil and form a black pasty deposit.

The cry for *high-flash-point compressor oils,* which comes up now and again after compressor explosions in mines, usually meets with a far too ready response. High flash point means high viscosity (large percentage of filtered cylinder stock in the oil), and this inevitably means more trouble with carbon deposit than ever.

In colliery compressors using air-compressor oils with a flash point of over 500°F. (steam-cylinder oils) the coal dust bakes

together with the oil and presents a smooth glossy surface, due to the pitch and tar contained in the coal dust. Such high-flash-point oils have one virtue, however, in that they do not give off much vapor exposed to the normal air temperatures in an air compressor. Their use is therefore justified—in fact, may be quite necessary—where lower-flash-point oils give off so much vapor that they affect the throats and lungs of the workmen in tunnel work, collieries below ground, air-worked machinery in confined spaces, etc. For such conditions, reasonably low-viscosity filtered cylinder oils should be employed. The flash point is no safe criterion as to the amount of vapor given off *below* the flash point. Speaking generally, *high-viscosity oils* act sluggishly and are inclined to retain much of the dust, particularly on the discharge valves, where the *maximum temperature exists.* When such oils are used, and the air is dirty, it must be filtered, and the compressor pipes and receivers should be frequently examined and cleaned, so that, notwithstanding the sluggish oil, the danger of explosions may be avoided.

Low-viscosity oils assist in maintaining the compressor in a clean condition, notwithstanding dirty surroundings; the dirt that gets in is kept moving and is largely passed through the compressor and out of the discharge valve into the discharge pipe, aftercooler, and receiver.

Soap and water are excellent for cleaning purposes, but their use as a lubricant does not dissolve existing deposits; in fact, more deposit is formed, as the water evaporates. In one case, a 2-in. deposit (which ignited at 400°F.) was formed inside the discharge pipe of a compressor, lubricated entirely by soap and water. Explosions have been reported to have occurred when soap and water have been used exclusively for lubrication, but the author has no personal knowledge of any such cases.

EXPLOSIONS

We have seen several reasons for the production of abnormally high temperatures. The heat emanates chiefly from the discharge valve or valves, and it is probably safe to say that fires or explosions originate at or near the discharge-valve chamber.

Exposed to high temperature, the accumulated oil or oily deposit will begin to emit vapor at 120 to 150°F. below the open

flash point of the oil. As the temperature increases, the oil will vaporize more vigorously; and when the temperature is well above the flash point, the mixture of oil vapor and air may easily accumulate in or near the discharge-valve chamber and be in the right condition to explode. Perhaps a small piece of deposit on the discharge valve begins to glow sufficiently to fire the mixture. A temperature of about 700°F. is sufficient to ignite the oil vapors spontaneously, and a fire or explosion follows.

Experience seems to show that in *large moderate-pressure compressors* explosions do not occur if the intake air is filtered or if deposits are not allowed to accumulate in too great quantities. When there are no deposits there can be no fire, therefore no explosions. The amount of oil used for lubrication in large compressors is so small compared with the large volume of air passing through the compressor that the oil vapors formed, even under high-temperature conditions, are so diluted that they cannot explode. If an explosion occurs, it is frequently too weak to burst pipings or receivers.

The high temperature may, of course, ignite accumulated oily deposits in the discharge pipe, in which case the fire will spread slowly to the receivers. The burning deposit may make the receiver walls red-hot, so that they burst, being unable to withstand the normal receiver pressure.

In one typical case of a colliery compressor the accumulation of coal dust and oil in pipes and receiver had not been cleaned out for 2 years; there was a weak explosion, and the deposit burned for a considerable time, causing men in the pit operating coal cutters to cease work owing to the obnoxious fumes in the compressed air.

In another case, a leaking joint on the discharge pipe close to the compressor had been "cured" by driving a piece of wood into the joint. The point of the wood protruded inside the pipe and ignited spontaneously, owing to abnormally hot discharge air. The fire spread to the receiver, and, the latter being opened up, 3 cwt. of deposit accumulated over 7 years was removed—or, rather, what remained after most of the combustible matter had burned away.

If the dust, which together with the oil forms the deposit, is itself inflammable, such as coal dust, the danger of the deposit's taking fire is, of course, greater than where it consists of non-

inflammable ingredients, such as fine sand and dust in quarries and iron mines.

In *multiple-stage high-pressure compressors,* where the volume of air discharged is comparatively small, the amount of oil used for lubrication and intermingled with the air is appreciable; and under conditions of abnormal temperatures, explosive mixtures of oil vapor and air are formed, which will bring about violent explosions, when the spontaneous-ignition temperature is reached. Such explosions may occur even if the amount of accumulated deposit is small.

Afterburning of deposit, which is a characteristic feature of most "explosions" in large moderate-pressure compressors, does not occur in high-pressure compressors. If an explosion occurs in the very confined spaces, it is very violent and usually shatters the piping, receiver, etc.

NOTE.—Valve pockets or discharge chambers and pipes should be so designed that there are no cavities where mixtures of oil vapor and air may remain stagnant.

Spontaneous-ignition Temperatures.—The temperature at which oil vapor and air ignite spontaneously, *i.e.,* without the aid of a spark, is *higher the lower the viscosity of the oil.* Speaking generally, the more complex and the more viscous a petroleum product is the lower is its spontaneous-ignition temperature. For example, kerosene ignites spontaneously in air at a lower temperature than gasoline. The compression in kerosene-oil engines is lower than in gasoline engines for this very reason, as the danger of preignition is greater with kerosene.

It will, therefore, be realized that the danger of explosions is not lessened by the use of very high-flash-point oils. Quite apart from the fact that such oils are extremely viscous and favor formation of deposits, the mixture of air and vaporized oil is spontaneously ignited at lower temperatures than with a lower viscosity oil. It might be asked, Why, then, not go to the other extreme and use very low-flash oils? Up to a certain point this view is certainly justified and correct. But with extremely volatile oils, although they will tend to keep the internal conditions clean and thus minimize danger of explosion, yet they vaporize so much exposed to normal compressor temperatures that the presence of vapors in the compressed air will become troublesome, and, furthermore, such oils will not satisfy the requirements as regards lubrication.

Too thin oils will not seal the pistons and will cause excessive internal friction and wear.

In view of what is said above, its seems probable that very few explosions have been caused on the discharge side of a compressor by injecting kerosene into the compressor for cleaning purposes; but when kerosene explosions have occurred they have usually been in the compressor cylinder itself, the ignition taking place through the suction valves on the approach of a naked light. For the same reason, no naked light should be used when opening up receivers or intercoolers for examination.

The following case shows, however, that the flame caused by the presence of kerosene may be carried right through the compressor and ignite a mixture of air and oil vapor on the discharge side.

In a compressor, in which the valves had been reseated and the cylinder cleaned out, the cleaning was done with kerosene. When the compressor was started up, the engine attendant came to the conclusion that something was wrong with one of the suction valves and took up a candle for the purpose of inspecting it. The result was an explosion, the discharge pipe being blown to pieces for a length of about 10 yd. It was evident that a quantity of kerosene was pocketed in the suction-valve chamber and that as the engine acquired the usual working temperature, after a short run, the heat was sufficient to vaporize the kerosene. When the engine attendant inspected the valve, the candle flame ignited the kerosene, the flame was carried through to the discharge pipe, and the explosion followed.

Air-compressor Rules.—The following rules should be observed in order to avoid danger of explosions:

1. Intake air should be taken from outside the engine room and should be cold, clean, and, if necessary, filtered.
2. A sparing and uniform amount of a carefully selected compressor oil should be supplied, with frequent drainage of intercooler and aftercooler for water and oil.
3. Good cooling of the cylinder should be practiced, including discharge-valve chambers, as abnormal temperatures emanate from these valves. The cooling water must always be turned on before the air compressor is started.
4. Temperatures should be taken regularly of intake and discharge air, as abnormal rise in temperature is a sure indication of trouble.

5. An aftercooler should be fitted in the discharge line before the receiver under difficult conditions, so that only cold air enters the receiver.

6. Compressor pressure gauges should be periodically examined and corrected by comparison with standard gauges.

7. There should be frequent inspection and cleaning of water jackets, valves, discharge pipe, aftercooler, and receiver; in multiple-stage air compressors, discharge valves should be examined every week; low-pressure valves, every month; receiver and coolers, every month to every 6 months, depending upon the conditions.

8. Kerosene should never be used for cleaning the compressor or pipes internally, as it evaporates and forms an explosive mixture with the air. Soap and water should preferably be used for cleaning, the surfaces being afterward wiped clean and oiled with compressor oil to prevent rusting while standing.

SELECTION OF OIL

Air-compressor oils, in view of what is said in the preceding chapter, should preferably be pale-colored straight-run distillates, highly refined and filtered, containing as few unsaturated hydrocarbons as possible. They should preferably contain little or no cylinder stock.

Where, in order to obtain a heavy viscosity, the admixture of filtered cylinder stock becomes necessary, the distilled oil should be as viscous as possible so as to minimize the percentage of cylinder stock required in the finished oil.

Air-compressor oils of four different viscosities are required to lubricate the cylinders and valves of all types of blowing engines and air compressors, as indicated in the table below.

COMPRESSOR OILS

Compressor oil, number	Viscosity number*	Viscosity at 50°C. in centipoises	Flash point open, degrees Fahrenheit	Flash point closed, degrees Fahrenheit
1	5	18	380	355
2	8	38	400	375
3	10	76	425	400
4†	13	165	510	475

* See table, p. 57.

† Compressor oil 4 is a filtered steam-cylinder oil.

These four oils are usually straight mineral oils; but for multiple-stage compressors, as Diesel compressors, oils 2 and 3 are recommended and should preferably contain from 3 to 6 per cent of a nondrying, acid-free, fixed oil.

The following chart gives specific recommendations for the various types of blowing engines and air compressors.

LUBRICATION CHART
For Blowing Engines and Air Compressors

Type of blowing engine or oil compressor	Number of stages	Final air pressure, pounds per square inch	Compressor-oil number
Blowing engines:			
Blowing cylinder horizontal, no tail rod......	Single stage	10 to 30	3
Horizontal, with tail rod..................	Single stage	10 to 30	2
Vertical................................	Single stage	10 to 30	1 or 2
Air compressors:			
Small:			
Compressing less than 1,000 cu. ft. of free air per minute			
Small compressors are usually enclosed and use the same oil for cylinders and bearings	Single stage	Below 70	1
	Two stage	Below 150	1
	Single stage	70 to 120	2
	Two stage	150 to 450	2
Large:			
Compressing more than 1,000 cu. ft. of free air per minute			
Horizontal cylinders, no tail rod..........	Single stage Two stage	Below 70 Below 150	3 or 4
Horizontal cylinders, with tail rod........	Single stage Two stage	Below 70 Below 150	2 or 3
For large compressors compressing above the pressures given....................			3 or 4
Large horizontal compressors are usually open type and use separate bearing oils externally			
Large vertical compressors are frequently enclosed type, employing force-feed circulation for the bearings, and the same oil is used throughout			

NOTE 1.—Where a compressor is delivering air to air-worked engines placed in confined spaces (tunnel work, etc.), use a heavier viscosity (less volatile) oil than the one indicated in the chart.

DRY-AIR PUMPS

Dry-air pumps, or *vacuum pumps*, *e.g.*, as employed in condenser plants for steam engines or steam turbines, are a kind of

air compressor; they compress the small amount of air leaking into the system and discharge it at atmospheric pressure.

Dry-air pumps are often constructed with slide valves, and the lubrication of these valves is troublesome and difficult. The oil is subjected to the vacuum under conditions of high temperature, owing to the surfaces' being in touch with hot steam and to the additional heat created by valve friction. The result is that the oil is distilled—"vacuum distilled"—and is oxidized by the air, forming a sticky carbonaceous deposit. The remedy lies in using the oil with the utmost economy and applying it regularly and uniformly, preferably by means of a mechanically operated lubricator. The less oil consumed the less carbon is formed. An excellent idea is to introduce a jet of steam through a ½-in. exhaust-steam pipe taken from the steam engine driving the air pumps, *e.g.*, in the Alberger pump. There must be no valves in this pipe; this admission of moist steam greatly minimizes the formation of carbon.

Many engineers, when they have experienced trouble with a medium-viscosity compressor oil, jump to the conclusion that by using a higher flash-point oil the carbonization will be overcome; they therefore use steam-cylinder oils, "the thicker the better," and find the carbonization much worse than before, notwithstanding their endeavor to use as little as possible. As the oil is volatilized during use, it is obvious that a distilled lubricating oil, which has already been volatilized when it was being manufactured, must have less tendency to leave a residue than steam-cylinder oils which are *undistilled.*

Experience proves that the best results are obtained by using compressor oil 2, as pale as possible, without cylinder stock and preferably slightly compounded so as to make it combine with the moisture, which is always present.

NOTE 1.—No. 4 compressor oil must be used only if there are very special reasons for using such a heavy-viscosity oil, *e.g.*, the necessity of having an absolute minimum of oil vapor in the compressed air or bad mechanical conditions in large horizontal compressors.

NOTE 2.—*Glycerin* must be used for compressors in breweries, as even slight traces of mineral-oil vapor in the air will be absorbed by the beer and affect the taste, whereas glycerin has no detrimental effect whatever.

NOTE 3.—For *three- and four-stage compressors*, the same oils are recommended as for Diesel compressors (see page 572), *viz.*, compressor oils 2 and 3 compounded with 3 to 6 per cent of fixed oil.

Similar conditions exist in a number of other vacuum pumps, *e.g.*, those used in connection with sugar-evaporating pans.

AIR-OPERATED ENGINES AND PNEUMATIC TOOLS

Compressed air is used for operating a variety of engines, machinery, and tools as indicated in the beginning of this section (page 422).

Air-operated Engines.—The operating temperatures of the engines, etc., determine what viscosity oil is to be used.

Air engines operating coal cutters are usually fairly warm and demand an oil like bearing oil 5 (see page 135). As the temperatures are never more than moderate, there is no danger of carbonization's taking place, so that a bearing oil of suitable viscosity will do all that is required. As a rule, the operating temperatures are low, particularly when the engines or tools operate with air *expansion*, because the air becomes cold when it expands.

Such low temperatures may bring about trouble by the lubricant's congealing or the engine's becoming choked with snow. The amount of moisture in the compressed air is often considerable. When, for example, warm compressed air is sent down the shaft in a coal mine, it cools, and some of the moisture condenses; if it is not efficiently drained out just before reaching the engine, it will freeze into snow, lodge in the exhaust port, and accumulate till the engine pulls up. Even if the lubricating oil does not congeal, it will not clear the exhaust, but an admixture of glycerin with the oil, say from 30 to 50 per cent, will usually thaw the snow and keep the exhaust clean. The mineral oil should have a cold test of, say, $-25°$F. for such extreme cases, but usually a zero cold test will be found satisfactory. Large air-operated hammers for forging purposes should preferably have the oil introduced by means of a mechanical lubricator, the movement being taken from the hand lever (see Fig. 158). For such large hammers medium-bodied oils are preferable, as the operating temperatures are very moderate.

A class of air-operated engine difficult to lubricate is the one in torpedoes. It may have three cylinders enclosed in a crankcase. The oil is forced into the main bearings, then through tiny holes in the crankshaft, say $\frac{1}{300}$ in., into the crankpins, while the pistons are lubricated by splash from the crankcase. The oily exhaust air from the engine may be used for lubricating some

of the gears. The oil is forced into the bearings by means of air pressure. Toward the end of the run the air pressure drops, and the oil supply diminishes, as the resistance toward the oil flow

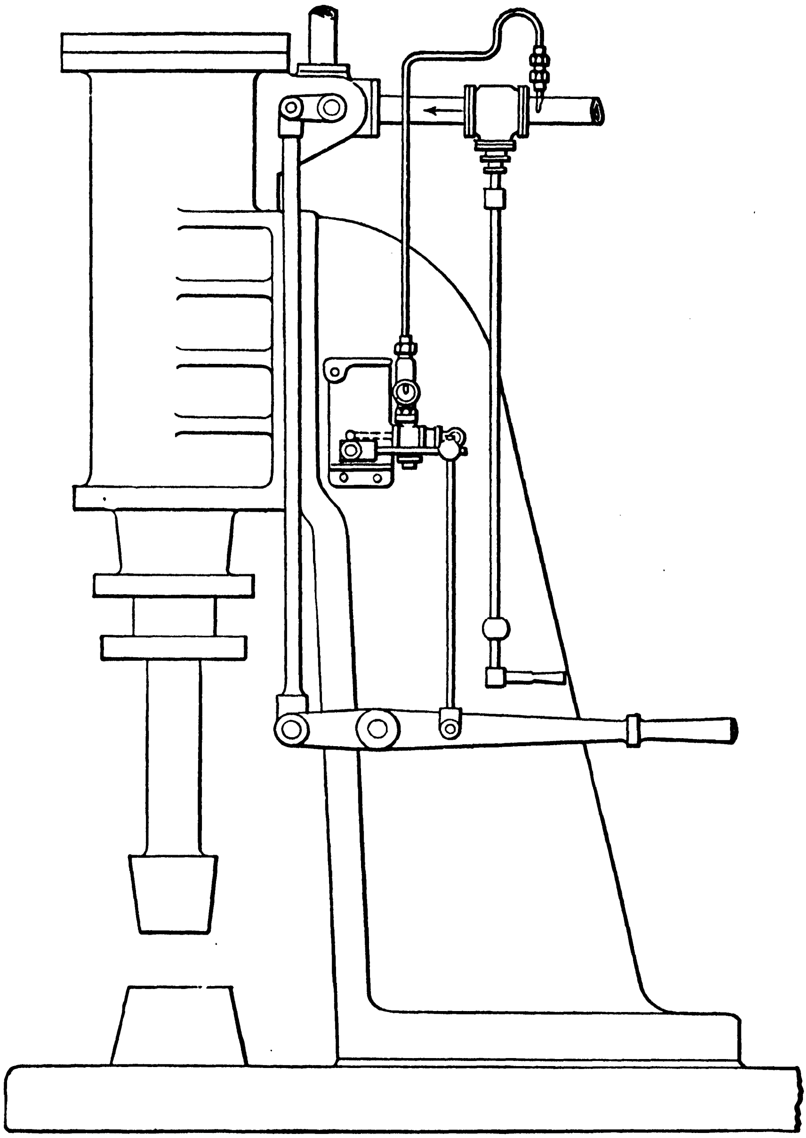


FIG. 158.—Air-operated hammer with mechanical lubricator.

through the tiny passages remains unaltered. Simultaneously, the air is heated to maintain sufficient engine power; the hot air burns and oxidizes the oil in the cylinders.

The conditions are therefore irregular oil feed, *i.e.*, *overfeeding* most of the time, and exposure to high temperatures and air

oxidation. All mineral oils produce too much carbon under these conditions. The oil that has given most satisfaction is *cold-pressed, highly refined, acid-free neat's-foot oil* or its equivalent. Such an oil has a very high flash point without being unduly viscous, and it gives practically clean lubrication.

Pneumatic Tools.—Pneumatic tools operate at very high speed (often several thousand strokes per minute), and the parts have exceedingly fine clearance. They are therefore very sensitive, and the air consumption may easily increase 25 per cent or more if too viscous oils are used. Oils for pneumatic tools should

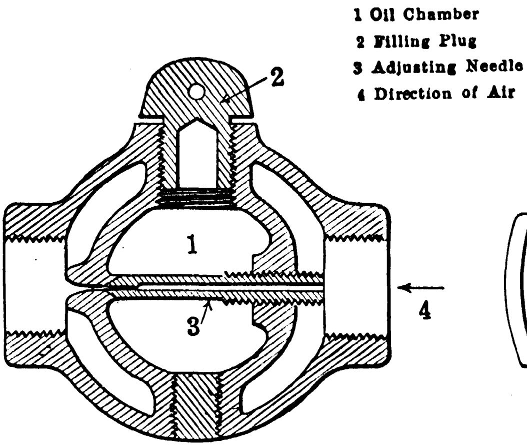


FIG. 159.

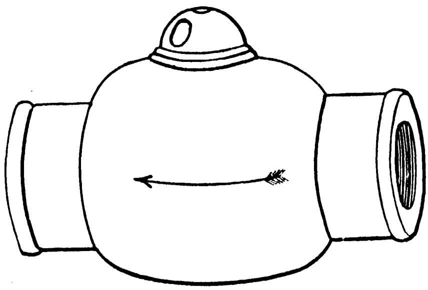


FIG. 160.

Pneumatic tool oiler.

therefore be very light-viscosity oils and have low—sometimes very low—cold tests to prevent them from congealing and clogging the tools. The oil is usually fed into the tool at intervals, say every hour. If a tool freezes up, an injection of glycerin will usually thaw the snow and clear the exhaust, after which the usual low-viscosity oil may again be applied.

Several attempts have been made to introduce the oil sparingly and uniformly into the air before it reaches the tool, so as to avoid *underlubrication.* Figure 159 illustrates an oiler with a needle adjustment valve used by the Chicago Pneumatic Tool Company. Figure 160 shows an outside view; the direction of the air must be indicated.

It has been found that delays caused by underlubrication and stoppage of tools are reduced as well as the cost of maintenance, when such oilers are used; the filling of the oil chambers can be

done in the toolroom at night, when the tools are made ready for the following day's service.

Great care must be taken to ensure that the air-supply piping and also exhaust piping (if the latter is fitted) are free from dirt and chips and that they are thoroughly blown out before final connection is made to the tool, so that no dust or foreign matter will be carried to the working parts, and the exhaust pipe will be clear. There is usually a strainer at the end of the branch air pipe to which the flexible hose is attached. This strainer is

LUBRICATION CHART

For Air-operated Engines and Pneumatic Tools

Air-operated engines:	
Air-operated *coal cutters* This oil also to be used for general lubrication of the coal cutter.	Bearing oil 5 (see page 135)
Air-operated *haulage engines*, etc.	Refrigerator oil 1 or 2 (see page 460) or mixtures of these with up to 50 per cent of glycerin where the exhaust is liable to choke with snow
Large air-operated forging *hammers*	Bearing oil 4
Belt-driven pneumatic forging hammers in which air is compressed and used as an air buffer	Air-compressor oil 2 (see page 436)
Air engines in *torpedoes*	Highly refined neat's-foot oil with a 0°F. cold test
Pneumatic tools:	
Large pneumatic drills, etc.	Refrigerator oil 1 or 2 (see page 460)
Smaller pneumatic tools	Light pneumatic-tool oil* (see below)
For gear cases in pneumatic tools	Filtered cylinder oil with a poor cold test, say 80°F.

* *Light Pneumatic Tool Oil:* Pale, straight-run distillate, highly refined, having a Saybolt viscosity at 104°F. of approximately 80 sec., and a setting point of -25 to $+15$°F. according to the temperature conditions under which the tools operate.

made of fine-mesh brass gauze or cloth and retains scale and impurities, which would otherwise injure the tools. Even a small piece of rubber of the air hose will put the tool out of action.

It is good practice to immerse pneumatic tools in a bath of gasoline or kerosene overnight, then blow them out under pressure and oil them thoroughly before use.

For lubricating the gears in many types of tools, a filtered, poor-cold-test, say 80°F., filtered steam-cylinder oil will give good service; it will be semisolid at ordinary temperatures. This

oil may be injected into the gearcase by a syringe, say every few working hours.

It is important that the compressed-air pipe system be properly drained, to prevent water from getting into the tools, as such water would cause rusting of the pipes and also of the working parts in the tools, besides clogging the tools with snow, when they operate with air expansion.

CHAPTER XXVII

REFRIGERATING MACHINES

Refrigerating machines are used for producing cold, being employed in a great variety of installations, such as ice-manufacturing plants, breweries, distilleries, dairies, sugar factories, chocolate factories, slaughterhouses, cold-storage plants, oil mills, margarine works, stearin works, paraffin works, chemical works of various kinds, artificial skating rinks, for domestic purposes in large houses or hotels, hospitals, etc., public mortuaries, mining operations (sinking shafts through wet sand), also in fishing vessels (freezing fish), food-transport ships, modern passenger ships, warships (cooling ammunition chambers), etc.

CLASSIFICATION

A great variety of refrigerating machines are in use; they can, however, be classified according to the system of refrigeration employed as follows:

Absorption machines.
Compression machines.

Absorption Machines.—These machies usually operate with ammonia. They are manufactured only by a small number of firms. No lubrication is required except for the circulating pumps, the lubrication of which presents no difficulty.

Compression Machines.—In these machines the cooling medium—the *refrigerant*—at one stage of the process is compressed; hence the name compression machines. They are built in all sizes, requiring from ½ horsepower for the smallest units up to 800 horsepower for the largest units in large installations.

According to the refrigerant employed, these machines may be divided into:

Cold-air machines.
Sulphurous acid machines.
Ammonia machines.
Carbonic acid machines.

The refrigerants are, respectively:

Air
Sulphur dioxide (SO_2)
Ammonia (NH_3)
Carbon dioxide (CO_2)

Cold-air machines are very bulky, and only a few machines are in existence. They were at one time used to some extent on board ship but have now been displaced by carbonic acid machines. They usually have two large cylinders. The air is compressed in one of these cylinders and expands and cools in the other. Glycerin is used for lubrication, as mineral oil gives the air a burnt odor, which taints meat.

Sulphurous acid machines are bulky—about two and one half times the size of ammonia machines—and are now seldom used. As the sulphurous acid is a lubricant in itself, no internal lubrication is required.

Ammonia machines and carbonic acid machines are practically the only two types of refrigerating machines employed in modern installations.

Ammonia machines are generally employed in land installations. They take less power to operate than carbonic acid machines, and the pressures carried in the system are considerably lower than the pressures in carbonic acid systems.

The principal objections to ammonia machines are that ammonia leaking out from the system has an unpleasant penetrating odor and is suffocating; on the other hand, the odor makes a leakage easily noticeable.

Carbonic acid machines are used almost exclusively on board ship; they take up considerably less room than ammonia machines. Carbonic acid is odorless; a leakage is therefore not easily detected, and good ventilating arrangements are essential.

During recent years, a variety of small high-speed refrigerating machines has been developed employing refrigerants such as methyl chloride (CH_3Cl), dichloroethylene ($C_2H_2Cl_2$), dichloromethane (CH_2Cl_2), and dichlorodifluormethane (CCl_2F_2).

Common to all these refrigerants is the fact that they dissolve mineral lubricating oils and therefore are not easily separated from the oil, as is the case with other refrigerants.

PRINCIPLE OF OPERATION

Figure 161 illustrates the main elements found in all refrigerating plants working on the compression system. The principle of operation, whether ammonia machines or carbonic acid machines are employed, is exactly the same, only the pressure and temperatures being different.

The following description is given for ammonia machines, the particulars in brackets referring to carbonic acid machines.

The elements are the following:

Compressor.
Oil separator.
Condenser.
Regulating or expansion valve.
Evaporator.
Dirt catcher.

The *compressor* (1) draws in gaseous ammonia from the suction pipe (7), leading into the suction valve. The ammonia is

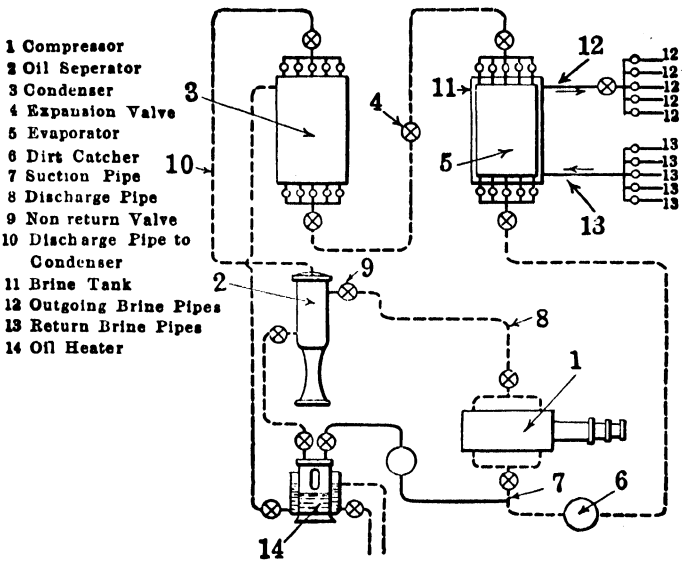


FIG. 161.—Refrigeration system.

compressed to a pressure of from 120 to 180 lb. per square inch (CO_2 from 900 to 1,200 lb. per square inch) and delivered at a temperature of 85 to 150°F. (CO_2 160 to 170°F.) through discharge pipe (8), through a nonreturn valve (9) into the oil separator (2), from which it is conveyed through a pipe (10) into cooling coils in the *condenser* (3).

Cold water passing through the condenser cools and liquifies the hot ammonia. The cold and liquified ammonia now passes through the *regulating or expansion valve* (4) into the coils of the evaporator (5).

The pressure in the *evaporator* coils is low, from 15 to 45 lb. per square inch (CO_2 from 200 to 400 lb. per square inch).

The effect of this considerable fall in pressure is that the liquid ammonia evaporates and in doing so cools down considerably below freezing point, the temperature being from $-20°F.$ to $+15°F.$ (CO_2: $-30°F.$ to $+15°F.$).

The cold evaporator coils are seldom placed directly where it is desired to produce cold. Usually they are placed in a tank (11), through which is circulated a nonfreezing brine (a salt solution); the brine, in passing over and around the cold evaporator coils, cools in contact with the coils. By means of a pump the cold brine can be pumped away through pipes (12) to the place where it is desired to produce cold. The brine returns through pipes (13) to the evaporator tank to be cooled again.

The ammonia vapor leaves the evaporator coils at a temperature slightly lower than the temperature of the brine and returns through the dirt catcher (6) to the compressor, continuing the cycle of operations just described.

During recent years, a new system of ammonia refrigeration, called the dry-compression system, has come into use. It operates on the same principle as those machines already described, which are wet-compression machines, the chief difference being that the temperature of the ammonia in passing through the compressor is from 160 to 190°F. higher than that in wet-compression machines. The heat developed in a dry-compression machine is so high that it becomes necessary to surround the compressor cylinder with a cooling-water jacket.

CONSTRUCTION

Small compressors are driven by belt or rope drive.

Large compressors are usually operated by a steam engine, the steam engine and the compressor having a common crankshaft. Sometimes the steam-engine cylinder is placed in tandem with the compressor cylinder. All compressors operate at low speed, as at high speed the operation of the valves becomes irregular. The

compressors are built either vertical or horizontal, the practice in this respect varying in different countries.

Most large compressors and many small ones are double acting, as the one illustrated in Fig. 162; but frequently *vertical* compressors are single acting, even in large sizes, there being only one suction valve and one delivery valve.

The cylinders of *ammonia compressors* are constructed chiefly of cast iron or steel, as copper or bronze parts would be attacked by ammonia. The cylinders of *carbonic acid machines* must be made very strong, on account of the high working pressure. They are generally made of a forged block of steel, suitably bored and finished.

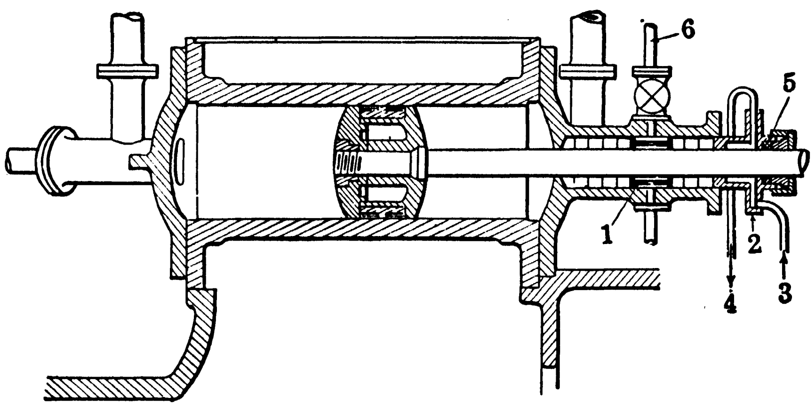


Fig. 162.—Ammonia compressor.

Stuffing Box.—The most important part of the compressor and the most difficult part to keep in good working order and well lubricated is the stuffing box. The object of the stuffing box is to prevent the escape of ammonia or carbonic acid from the cylinder and also to prevent outside air or moisture from entering the compressor through the stuffing box.

Figure 162 illustrates one type of ammonia-compressor stuffing box. The bottom ring consists of white metal; the packing rings are of cotton, saturated with oil. (1) is the so-called "lantern" which has a hollow space filled with oil around the piston rod; then follow more cotton packing rings, and sometimes a rubber ring, all the packing rings being squeezed together by means of the stuffing-box gland (2). For sealing this gland, oil is introduced through the inlet (3), and overflows through the outlet (4). Oil

is prevented from creeping out along the rod by means of the small stuffing box (5).

The oil film on the piston rod absorbs ammonia vapors from the inside of the compressor. These ammonia vapors escape in the lantern and rise through the pipe (6), from which they are passed over into the suction pipe of the compressor, so that no refrigerant is lost.

As the oil film swells on the piston rod inside the compressor, owing to absorption of ammonia or CO_2, a portion of oil is

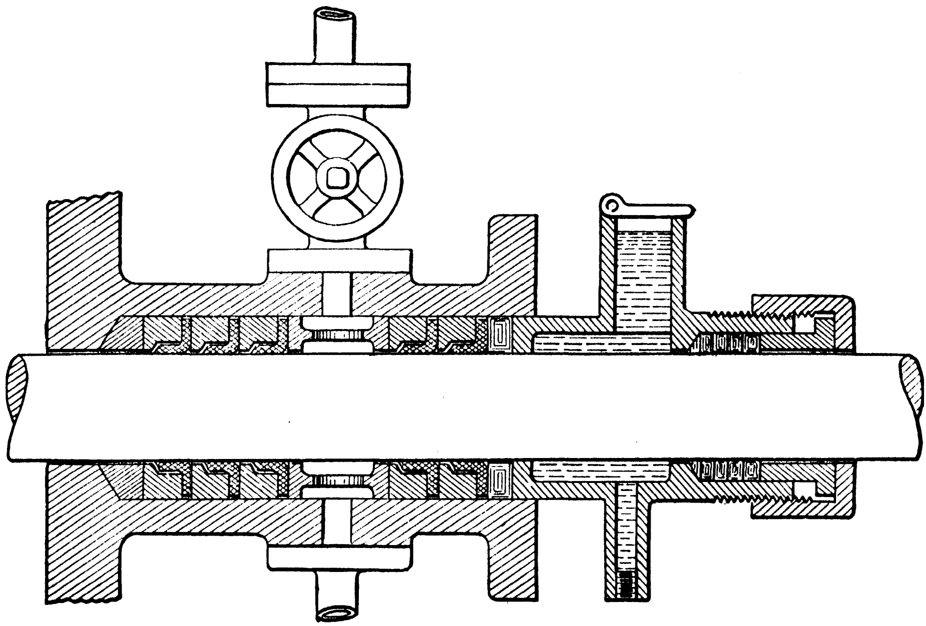


FIG. 163.—Stuffing box with leather packing.

continuously scraped off by the gland on the outward motion of the piston rod, and this oil serves to lubricate the piston.

As rubber is destroyed by the action of mineral oil and swells when absorbing CO_2, most manufacturers have discontinued its use in gland packings in favor of metallic or leather packing.

Figure 163 shows one form of stuffing box for a CO_2 machine. It is very accurately machined, and in the bottom is introduced a bronze ring, after which three sets of bronze rings and leather rings are introduced, then the lantern to which the oil is applied under pressure, subsequently two sets of bronze rings and leather rings followed by a ring of cotton; and then the stuffing-box gland keeps the whole packing in position. The bronze rings are

all a good fit against the inside of the stuffing box but do not touch the piston rod. The leather packing rings are thinned out toward the cylinder so that they form an elastic edge, and the pressure in trying to escape from the cylinder automatically causes the leather rings to press against the piston rod and thus to prevent leakage. The life of the leather packing is usually one season, sometimes two.

In some stuffing boxes there is an oil well near the front portion of the gland, covered with a lid. The gland should be so adjusted

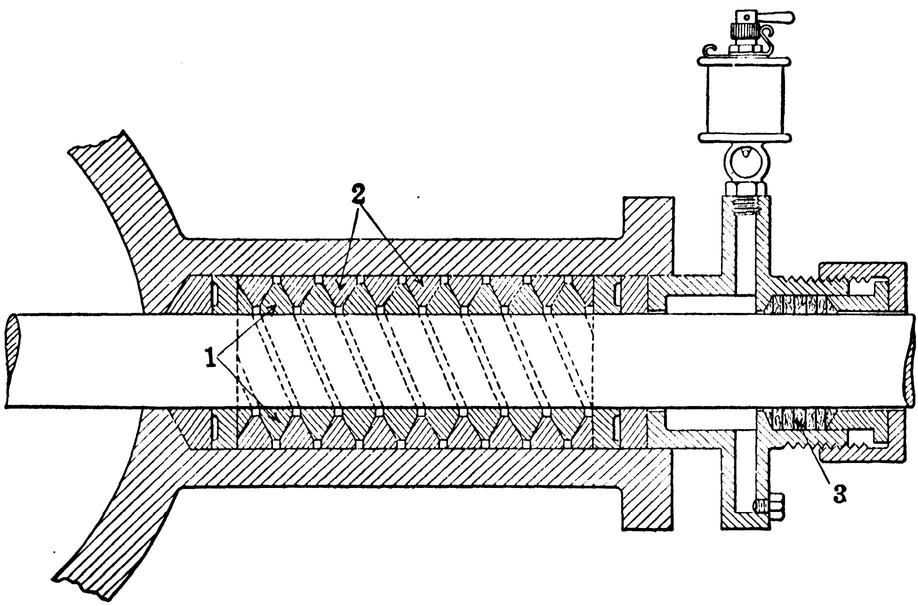


FIG. 164.—Stuffing box with metallic packing.

that occasional bubbles of CO_2 are to be seen rising from this well, but there should not be sufficient CO_2 escaping to cause foaming. If there are no bubbles, the packing is too tight.

Figure 164 illustrates a metallic packing built up of two spirals screwed into one another, the spiral (1) being of white metal and of triangular section; this gets squeezed tightly against the rod when the stuffing-box gland (3) is tightened up. The spiral (2) is also of triangular section but made of steel and forces itself toward the walls of the stuffing box, leaving spaces near the rod where the lubricating oil can accumulate for the purpose of lubricating the piston rod. The small stuffing box serves the same purpose as in Fig. 162. When this gland is in good condi-

tion and properly adjusted, only very little oil reaches the interior of the compressor.

In *dry-compression machines*, packings containing cotton, leather, or rubber cannot be employed, as they will be destroyed by the heat. Metallic packings are used, as the one illustrated in Fig. 164. Another type of metallic packing used for dry-compression machines consists of a number of rings, each in two halves surrounding the piston rod and pressed lightly against the rod by means of garter springs. The rings are held in accurately finished chambers, forming a casing around the piston rod.

When packings are renewed, or when a new compressor is started, it is important to tighten regularly and evenly all round, as soft packing becomes softer through use. If the packings are screwed up tight at once, the rod will probably heat, the packing may be destroyed, and the rod will get scored.

Oil Separator.—The greater portion of the oil reaching the compressor cylinder passes out of the compressor with the refrigerant and must be separated out by means of an oil separator, for reasons given later on.

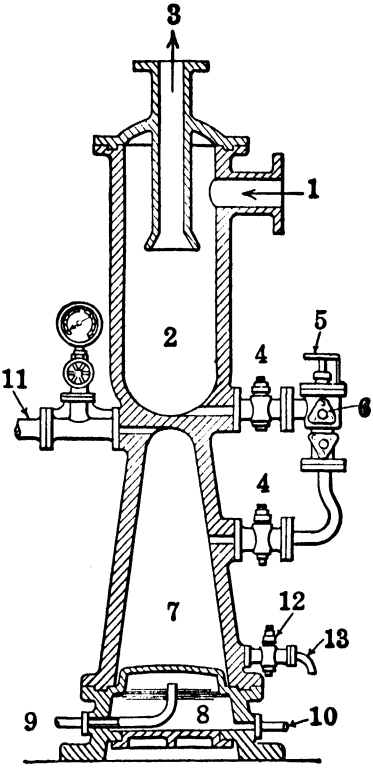


FIG. 165.—Combined oil separator and heater.

Figure 165 illustrates a typical oil separator, located in the engine room near the compressor. The hot gases enter through the tube (1) and leave the separation chamber (2) through the pipe (3). The oil is separated and accumulates in the bottom of the chamber (2), from which, by opening the cocks (4) and a needle valve (5), it is allowed to pass through the sight-feed arrangement (6) into the bottom of the chamber (7). Below this chamber is a heating chamber (8) through which hot water is passed, entering through pipe (9) and leaving through pipe (10). When the oil has been drained into the chamber (7), the needle valve (5) and shutoff cocks (4) are closed; the hot-water service is

put on; and the heat frees the oil from the ammonia vapors, which are passed out through the pipe (11), leading into the suction pipe of the compressor. Having been freed from ammonia vapor, the oil is blown out through the drawoff cock (12) and pipe (13).

In some oil separators a mechanically operated rotating plug is continuously transferring the separated oil from the separator (2) into the chamber (7).

Great care should be taken in filtering and purifying oil reclaimed from the oil separator, as, if it is not entirely freed from impurities, the result when using it over again will be the wearing of the piston rod, piston, and cylinder walls.

Expansion Valve.—The expansion valve is fitted for the purpose of wiredrawing the refrigerant from the high pressure existing before to the low pressure existing after the valve. It must therefore be capable of very fine adjustment.

If any water gets mixed with the refrigerant, this water usually freezes in the expansion valve and clogs it; impurities have the same effect; for this reason it is very important that the expansion valve be kept absolutely clean.

Dirt Catcher.—In the suction line of the compressor is fitted a short piece of pipe provided with a sieve, for the purpose of preventing impurities, such as iron scale, little pieces of packing material, or even ice (frozen water) from entering the compressor. This sieve should be examined every day or so in the case of a new compressor installation, every 3 days for the next couple of weeks, and later on once every 2 months. If the sieve in the dirt catcher is allowed to get full of impurities, it may unexpectedly burst. All the impurities will at once be drawn into the compressor and almost certainly cause serious damage.

METHODS OF LUBRICATION

The lubrication of the compressor piston and cylinder is brought about entirely by the oil carried through to the interior of the cylinder from the stuffing box by the piston rod.

There are three principal methods of lubrication, *viz.:*

Bath oiling system.
Mechanically operated lubricator.
Splash oiling.

Bath Oiling System (Fig. 166).—Oil is pumped continuously by means of a small oil pump through the pipe (1) into the gland (2)

surrounding the piston rod (3); it overflows from the top through the pipe (4) back again into the oil container, reentering the oil pump and circulating afresh.

Figures 167 and 168 show a bath oiling system, where the oil is not circulated but seals the gland by maintaining a height of oil above the lantern in the gland. In Fig. 168 the oil flows to the gland under the full compression pressure.

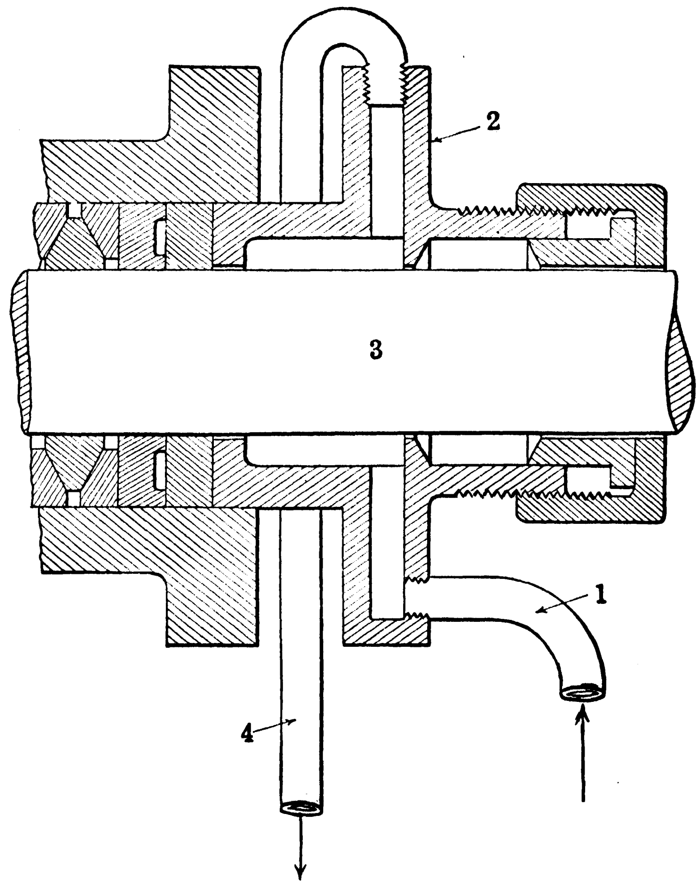


FIG. 166.—Bath oiling system for stuffing box.

When the stuffing-box gland packing is too loosely adjusted, an excess amount of oil will find its way into the compressor. On the other hand, if the packing is adjusted too tightly, too little oil will reach the interior; the piston rod will heat and may even become scored through the extreme friction and pressure exerted upon the rod in the gland; also, the packing will suffer from the heat; cotton or leather becomes brittle, and small portions may be carried into the cylinder, causing excessive wear.

Mechanically Operated Lubricator.—In dry-compression machines experience has proved the necessity of employing mechanically operated force-feed lubricators, which will introduce a small quantity of oil with precision and regularity and in which the

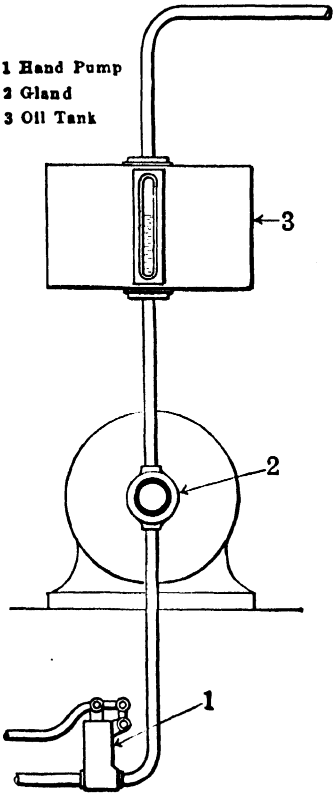


FIG. 167.—Bath oiling system with overhead tank.

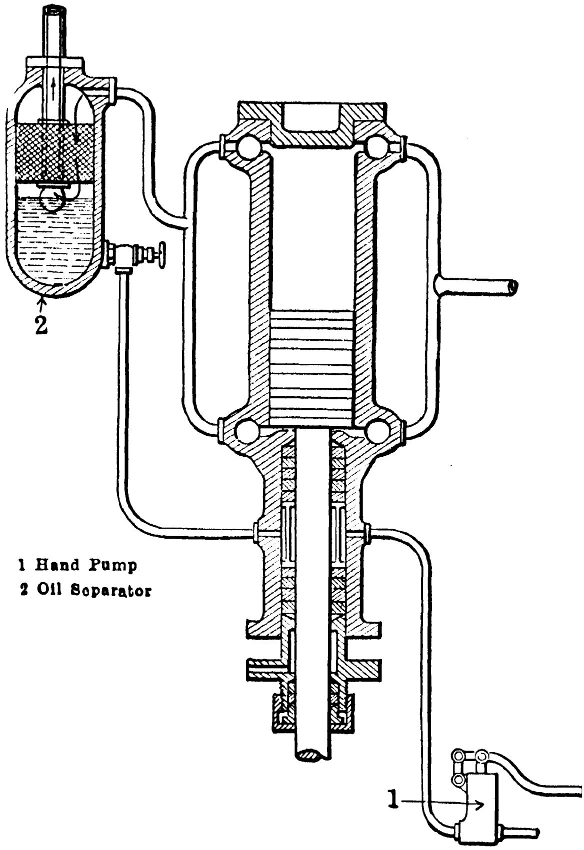


FIG. 168.—High-pressure bath oiling system.

oil feed can be adjusted to a nicety. The mechanically operated lubricator is driven from a moving part of the engine, therefore starts and stops feeding with the engine and delivers the required quantity of oil under pressure into the interior of the stuffing box.

Whereas the lubricating oil in *wet-compression machines* readily adheres to the moderately warm piston rod and thus ensures sufficient oil's reaching the interior, the case is different in *dry-compression machines.* Because of the high temperature of the piston rod, the oil film will be thin, and very little oil will reach

the interior of the compressor, unless it is introduced into the packing under pressure. That is the reason why mechanically operated force-feed lubricators are used, as in this way the oil is certain to be carried along the piston rod into the compressor, and

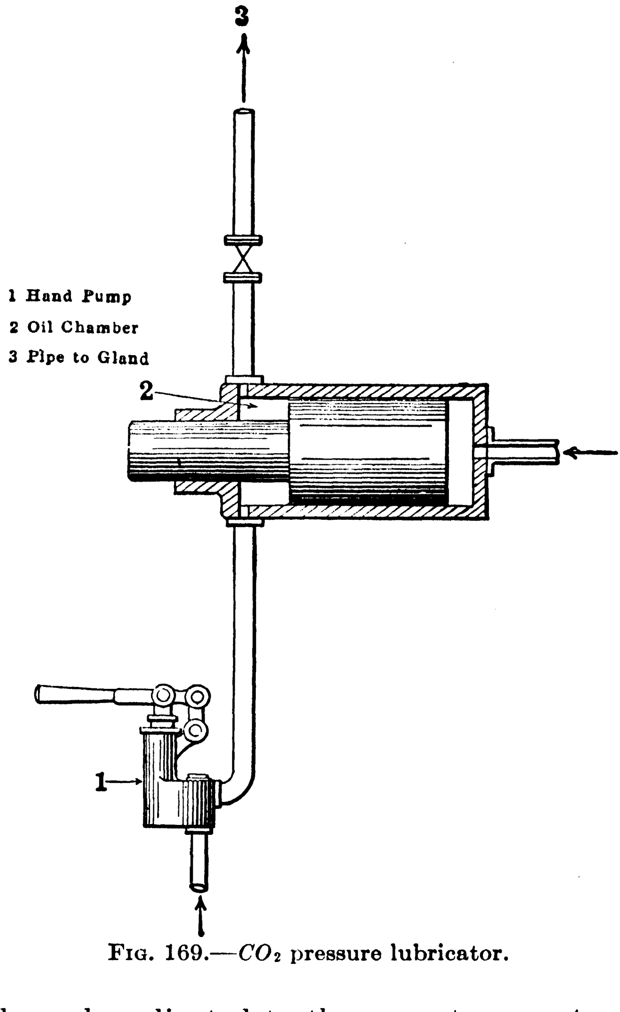


FIG. 169.—CO_2 pressure lubricator.

the oil feed can be adjusted to the correct amount required for piston lubrication.

It is important that a type of mechanically operated lubricator be used that will feed oil only. Several types of mechanically operated lubricators feed air with the oil; the air thus introduced into the stuffing box is drawn into the compressor, increasing the pressure in the whole plant and considerably decreasing the efficiency.

Figure 169 illustrates diagrammatically a lubricator for CO_2 machines which delivers the oil into the gland under pressure, the same as a mechanically operated lubricator, but is not capable of such accurate adjustment or control. It consists of a cylinder in which there is a piston with a piston rod. The one side of the piston is subjected to the condenser pressure of, say, 70 atmospheres. The other side (where the piston rod is) holds the oil and has an outlet fitted with an adjustable throttle valve, through which the oil passes out to the gland.

The difference in area between the two sides of the piston is about 10 per cent and causes the overpressure which forces the oil into the gland. By this method leakage of CO_2 from the gland is entirely obviated, and the outer gland is only required to prevent leakage of lubricant.

Splash Oiling.—Some few makes of small vertical enclosed-type ammonia and CO_2 compressors have a bath of oil in the crankcase, into which the crankpin bearing dips and splashes the oil to all parts.

The oil level should be a little below the underside of the crankshaft; if it is too high, the oil will froth with the vapors of the refrigerant, which are continuously drawn through the crank chamber.

LUBRICATION

The objects of internal lubrication of a refrigerating compressor are (1) to lubricate; (2) to form an oil-sealing film so as to prevent leakage of refrigerant past the piston and out through the stuffing box; (3) to preserve the leather or rubber which may form part of the packing material.

If *too little oil* is used, the oil film will not be complete, so that excessive friction and wear take place, and leakage past the piston and piston rod occurs.

If *too much oil* reaches the interior of the compressor, or if the separator is not sufficiently effective, a fair amount of oil will be carried over into the condenser and through the expansion valve into the evaporator coils, where, owing to the low temperature, it becomes sluggish and is only slowly carried through the coils back again to the compressor.

The *oil,* in passing through the compressor, is exposed to the effect of the ammonia or carbonic acid, under moderately high

temperatures. The result is more or less decomposition indicated by a darkening in color and an increase in gravity and viscosity.

Where the bath oiling system is employed, the system must be recharged with fresh oil, say once every year.

Oils with *too high a cold test*, when carried over into the separator coils, congeal on the inside of the tubes, and, as oil is a bad heat conductor, the capacity of the condenser and evaporator will be appreciably reduced. It is therefore important that the oil should possess a sufficiently low cold test so as not to become too sluggish to flow if it is carried over into the evaporator coils.

The oil must not contain any *moisture*, as the moisture will freeze and cause it to congeal. For this reason, engine attendants should be warned not to put the oilcans near suction pipes covered with snow in the vicinity of the compressor, as water dropping from the outside of such pipes may drop into the cans and contaminate the oil. Care should also be taken that the save-alls fitted under compressor glands and elsewhere to receive the waste oil are so made that no water dropping from the outside of the suction pipes can get into them and mix with the oil. Cases have been known where so much congealed oil has accumulated in the coils of the evaporator that they have become almost inoperative.

The oil for splash-oiled vertical compressors must have a *very low viscosity*, as otherwise it froths with the refrigerant; the froth fills the crank chamber, passes the piston, and clogs the whole system.

Even under the best conditions a slight amount of oil will certainly get over into the evaporator coils in all types of compressors, and it is therefore advisable to have the coils thoroughly and regularly cleaned. They are best cleaned by blowing through dry steam and afterward air to dry the pipes. In bad cases, this treatment may be preceded by the application of a solution of soda ash.

Glycerin is used as a lubricant where the packing of the piston or stuffing box consists partly of rubber, which in time is destroyed by mineral oil, whereas glycerin has no appreciable deleterious effect on rubber or leather. With a packing containing only leather and brass or white metal, as in Figs. 163 and 164, mineral lubricating oils are used and, if properly selected and of

good quality, will be found superior to glycerin in reducing the piston and gland friction.

With efficient lubrication the piston rod assumes a smooth glossy surface, covered with a thin clean film of oil, and the piston rod maintains a moderate temperature. The stuffing box, as well as the piston, will be perfectly sealed, so that no leakage of refrigerant occurs.

IRREGULARITIES

Where irregularities occur in a refrigerating plant, the effect is always to reduce its capacity for producing cold. The cause of the irregularity is not always easy to trace.

The following are typical causes of trouble:

Broken valve springs, preventing the valves from operating.

Leaky valves.

Leaky piston, piston rings out of order.

Dirty condenser coils: deposit from dirty cooling water on the outside, or a coating of oil on the inside of the tubes.

Expansion valve clogged or frozen (due to moisture in the oil, the use of poor cold-test oil, or impurities from the pipes).

Inefficient operation of the evaporator (due to oil or moisture's congealing on the inside of the tubes or to salt incrustations from the brine on the outside of the tubes).

Too little ammonia or carbonic acid in the system (due to leakage from the pipes or stuffing box).

The presence of air in the system, usually indicated by too high pressure in the system (air admitted through stuffing box).

ICE MAKING

A number of ice-making plants ashore are steam driven. The steam after passing through the steam engine is condensed and subsequently used for the manufacture of can ice. Plate ice is *not made* from *condensed* steam.

The cylinder oil used for internal lubrication of the steam engine may find its way into the ice, and this is most objectionable, as it discolors the ice and gives it an unpleasant odor and taste.

Troubles with discoloration of the ice can, however, be traced to a variety of causes, such as the boiler water, the raw "make-up" water, the exhaust-steam oil separator, and the water filters.

Water.—The water used as boiler feed water for the boiler must be specially selected; it must not be hard; it must be free from sodium, calcium, or magnesium; it should be neither acid nor alkaline or, at the most, should show only a slight reaction.

The boiler should be of ample capacity for developing the amount of steam required; the water level in it should never be allowed to rise too high and should be as constant as possible; otherwise, priming of the boiler occurs, and salts in solution and impurities will be carried over with the steam into the steam engine and finally mix with the water used for ice making.

Unsuitable water, used in the boiler or as raw make-up water, produces discolored ice.

Oil Separator.—It is the duty of the oil separator to remove as much as possible of the oil contained in the exhaust steam. The oil and moisture from the steam separate out in the bottom of the separator and are removed at regular and frequent intervals, automatically or nonautomatically. Most of the oil not caught by the oil separator will separate out in the reboiler (in which the water is heated and freed from air bubbles) and is automatically skimmed off the surface. Any traces of oil still left should be caught in the water filters (coke, charcoal, or gravel).

Filters.—Rust from the pipes and impurities of various kinds gradually accumulate in the filters. It is therefore necessary to clean or renew the filtering material at least once every season.

Steam-cylinder Oil.—When using compounded steam-cylinder oils, particularly dark cylinder oils, some of the oil may pass not only the oil separator but also the reboiler and even the filters, finally appearing in the ice.

Filtered cylinder oils separate easily from the water. A good grade of filtered cylinder oil is therefore to be recommended for steam engines in ice-making plants; and if a good type of mechanically operated lubricator is employed, so that the oil can be introduced in the best manner and used economically, the use of a compounded filtered cylinder oil in place of a straight mineral oil is permissible, containing not more than 3 per cent acidless tallow oil, as the admixture of tallow oil will enable the cylinder oil to be used exceedingly economically, and better lubrication will be obtained.

The little oil that will be present in the exhaust steam is easily taken care of by the oil separator or, at any rate, by the reboiler or filters.

LUBRICATION CHART FOR REFRIGERATING MACHINES

Refrigerator oils must be straight mineral oils. Compounded oils have too high a setting point; they combine to some extent with ammonia, more or less saponification taking place, and they are rather inclined to absorb moisture from the atmosphere, which is very undesirable. Only low viscosity is required, the setting point being of supreme importance.

For most refrigerators in ice-making plants an oil with a zero cold test will be satisfactory, but many CO_2 machines operate with lower evaporator temperatures than is the case in ice-making plants. A cold test of $-25°F.$ will, however, satisfy the vast bulk of refrigerating compressors. Many ice-making plants prefer to use an oil with a better cold test than 0°F. in order to have an extra margin of safety against the oil's congealing in the system.

Oils specially low in viscosity are required for small splash-oiled vertical compressors to avoid frothing.

To withstand the heat in the compressor without serious decomposition, refrigerator oils should be highly refined and highly filtered, pale-colored, straight-run distillates, containing as few unsaturated hydrocarbons as possible.

Experience proves that three mineral refrigerator oils having the viscosities, setting points, and open flash points shown below will satisfy all requirements.

Refrigerator oil, number	Viscosity number*	Viscosity at 50°C. in centipoises	Setting point, degrees Fahrenheit	Flash point open, degrees Fahrenheit
1	4 to 6	13 to 20	0	340 to 380
2	4 to 6	13 to 20	−25	320 to 360
3	1 to 2	4.5 to 8	Below −40	Above 300

* See table, p. 57.

These three mineral oils and glycerin are recommended for the following types of compressors:

LUBRICATION CHART
For Refrigerating Compressors

Machine	For compressor	For bearings
Cold air	Glycerin	Bearing oil† 4
Ammonia,* open type	Refrigerator oil 1 or 2	Bearing oil† 3 or 4
Carbonic acid,* open type	Refrigerator oil 2	Bearing oil† 3 or 4
Small, vertical, enclosed type, splash oiled, whether ammonia or carbonic acid	Refrigerator oil 3	Refrigerator oil 3
Large, vertical, enclosed type, splash oiled, whether ammonia or carbonic acid	Refrigerator oil 2	Refrigerator oil 2
Methyl chloride and similar small machines	Refrigerator oil 2	Refrigerator oil 2

* When rubber forms part of the packing in the stuffing-box gland, glycerin must be used and not mineral refrigerator oil.

† For bearing oils see page 135.

CHAPTER XXVIII

GAS ENGINES

In order that the reader may understand and appreciate the lubricating problems met with in connection with gas engines, it becomes necessary to give first of all a picture of the mechanical and operating conditions.

The subject has been divided into "Small and Medium-size Horizontal Gas Engines," "Large Horizontal Gas Engines," and "Vertical Gas Engines." For each group of engines particulars of typical engines and the methods of lubrication are given. Some information follows in regard to cooling and gas, both of which have an important bearing upon the lubrication of gas engines. The formation of carbon deposits is then treated in detail, and finally the important part played by the oil itself, and the correct grades to be recommended for the principal types of engines.

SMALL AND MEDIUM-SIZE HORIZONTAL GAS ENGINES

Classification.—Small horizontal gas engines have only one cylinder; they develop from 1 to 50 hp. and operate at high speeds, ranging from 500 to 190 r.p.m. Medium-size horizontal gas engines are made with one or two cylinders; the power developed per cylinder ranges from 50 to 250 hp., and the speeds range from 190 to 130 r.p.m.

The cylinders are always water cooled, and where the power per cylinder exceeds 150 hp. the *piston* must also be water cooled. Indeed, many builders employ water-cooled pistons in engines ranging in sizes from 80 hp. per cylinder upward.

Small and medium-size engines are practically always of the four-stroke-cycle type and, in view of the foregoing, may be classified as shown in the table on page 463.

The cylinders of medium-size engines may be arranged in various ways (Fig. 170):

Two cylinders, opposed—*the opposed-type engine* (Fig. 170*A*).

Two cylinders, one behind the other—*the tandem engine* (Fig. 170*B*).

Two cylinders, side by side—*the twin engine.*

Size	Number of cylinders	Horse-power per cylinder	R.p.m.
Small size	1	1 to 50	500 to 190
Medium size (without water-cooled pistons)	Usually 1; sometimes 2, 3, or 4	50 to 150	190 to 140
Medium size (with water-cooled pistons)	Usually 1; sometimes 2, 3, or 4	80 to 250	180 to 130

Three or four cylinders, side by side—*the multiple-cylinder engine* (Fig. 170*C*).

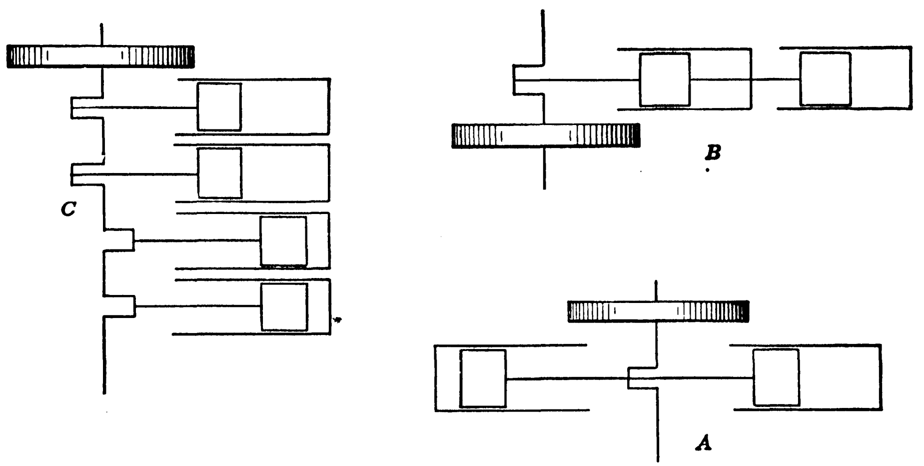


FIG. 170.—Types of horizontal gas engines.

Principle of Operation.—The four-stroke-cycle principle of operation may be described as follows:

First or Suction Stroke.—Gas and air, constituting the fuel charge, are sucked into the cylinder through the open inlet valve as the piston moves away from the cylinder head. The exhaust valve is closed.

Second or Compression Stroke.—The piston moving toward the cylinder head compresses the fuel charge. Both inlet and exhaust valves are closed.

Third or Power Stroke.—Ignition by the spark of the compressed fuel charge produces explosion and expansion of the gases, forcing the piston away from the cylinder head *during the power stroke.* Both inlet and exhaust valves are closed.

Fourth or Exhaust Stroke.—The piston moving toward the cylinder head drives the burned gases out through the open exhaust valve. The inlet valve is closed.

Thus the four strokes of the piston, *i.e.*, one power and three preparatory strokes, complete the cycle of events; hence the expression four-stroke cycle.

Methods of Lubrication. *Main Bearings.*—These are generally ring-oiled bearings, having an oil reservoir from which one or two revolving oil rings continuously carry the oil to the bearing surfaces. In some medium-size gas engines the main bearings are, however, fed by gravity from an elevated tank and kept in continuous circulation by a pump.

Crankpin Bearing.—This is lubricated by means of the well-known banjo arrangement. Either the oil is fed into the banjo from a sight-feed drop oiler, or the feed may come from a mechanically operated lubricator.

Piston.—Small engines are often fitted with only one oiler to supply the piston and wrist pin. The surplus oil on the piston collects in a groove at the top and through a tube drops into the wrist-pin bearing, more or less contaminated with carbon. With this method it is always necessary to overfeed the piston in order to ensure a reasonable supply of oil's reaching the wrist pin. Many small engines and most medium-size engines have therefore separate oilers for piston and the wrist pin, so that the right amount of oil can be distributed.

The piston oiler, if it be a sight-feed drop oiler, should preferably be provided with a ball check valve to prevent blowback of escaping gases into the sight feed (see Fig. 18, page 116).

Gravity sight-feed drop oilers will vary from, say, 40 drops per minute when nearly full to 16 drops per minute when nearly empty. If the quantity fed at a lower level is sufficient, as it must be if the engine is not to suffer, the extra quantity fed when the container is full is sheer waste and, in the case of the cylinder, positively detrimental. The oil feed is very susceptible to temperature changes, and the needle valves easily choke with dirt. The idea has therefore been steadily gaining ground that something more reliable is needed, and the foremost engine builders are adopting a centrally placed multifeed lubricator operated mechanically from the camshaft. The lubricator should be designed on principles that will ensure a constant uniform oil feed, independent of the height of the oil level in the container

and independent of the viscosity of the oil. Each feed should be from a separate pump unit, independent of the other feeds, and should preferably have a sight-feed arrangement showing the oil on its way to the engine; also, the feeds should be capable of being flushed and of instantaneous adjustment between wide limits.

The lubricator usually has an operating lever actuated by a cam on the camshaft; the oscillating lever gives motion to the internal mechanism in the lubricator, so that pump plungers automatically pump oil through the various oil pipes. The individual feeds of the lubricator, once adjusted, require no further attention.

In order to ensure that the oil pipes shall be always full, they should be provided at the extreme ends with check valves.

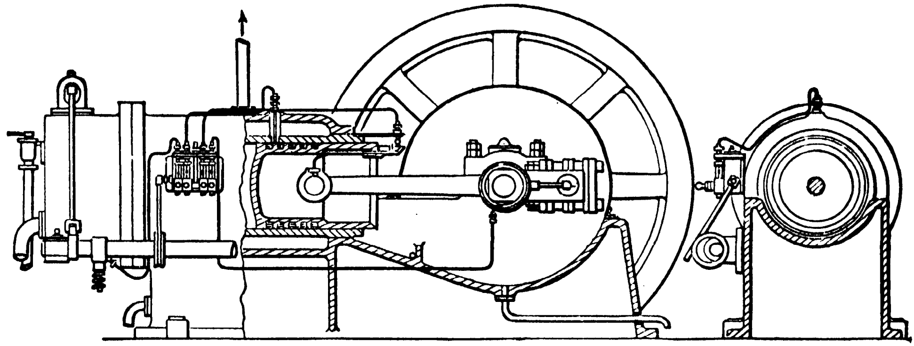


Fig. 171.—Timed oil injection to piston of gas engine by a mechanical lubricator.

When the lubricator is stopped, and the pumps cease to operate, the check valves prevent the oil from running out of the pipes. The pipes are thus kept constantly full of oil, and instant lubrication is assured whenever the engine and, consequently, the lubricator starts to operate.

Timed Oil Injection to the Piston (Fig. 171).—When the mechanical lubricator is designed to pump oil only and not oil and air, the piston oil feed can be timed to inject the oil under pressure at the right moment and to the ideal place, which is between the first and second piston ring, when the piston is at its most outward position. This enables the piston to carry the oil well into the cylinder. Feeding the oil in this way, the piston will act as an oil distributor; cleaner and more economical lubrication of the piston is obtained, and practically no oil runs to waste from the lip of the liner. It is necessary that the oil should be

fed through a combined check valve and oil injector (see Fig. 172), the end of which barely touches the piston, so that for every impulse of the oil pump a small portion of oil is wiped off by the piston and taken right into the inner portion of the cylinder, distributing itself uniformly over the entire surface. Any deviation from this practice, either by feeding the oil nearer the front of the liner than indicated or by feeding it through a lubricator that does not time the injection of the oil, will mean a larger oil consumption (waste), more carbon deposit, and a lower margin of safety.

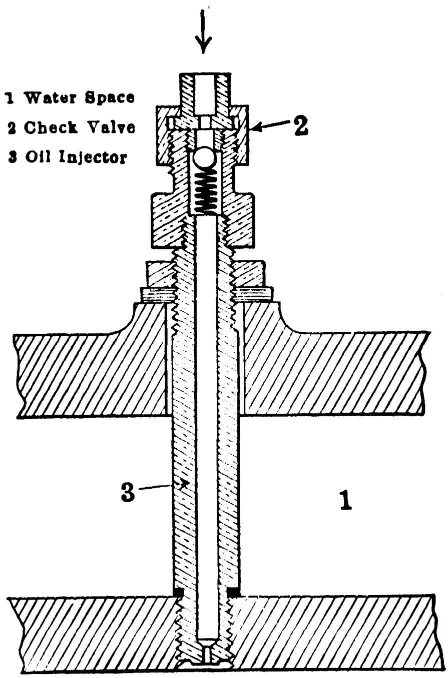


Fig. 172.—Oil injector.

On the Continent, practically all gas engines are fitted with some kind of mechanical lubricator, so as to ensure that the oil feed to the piston shall be as regular as possible, but the importance of timed injection does not appear to be fully realized. The installation of such a mechanical lubricator means extra initial cost to the consumer and to the engine builder, but it also means a saving in oil consumption as compared with sight-feed drop oilers of as much as 50 per cent, and, what is much more important, it means a greatly increased margin of safety, as well as cleaner and more efficient lubrication throughout.

One engine builder who had for years been using sight-feed drop oilers in connection with pumps (the oil dropping from the sight-feed drop oilers into the oil pumps) found that after installing mechanical lubricators of a good make, practically all their trouble during the guarantee period of their engines ceased. In many cases, engine attendants forget to adjust the sight-feed drop oilers, forget to start them or stop them, or allow them to run empty. With a mechanically operated lubricator there is only one container to fill, and one filling of the container will last several days; less attention is therefore required!

Valve Spindles and Cams.—The valve spindles of inlet and exhaust valves (as well as the cams) are sparingly hand oiled, but in the case of larger gas engines, say above 50 hp., it is becoming general practice to lubricate the exhaust-valve spindle by one of the feeds from the mechanically operated lubricator. The feed must be very sparing and absolutely uniform. With an excessive oil feed the excess oil burns and carbonizes. With too sparing a supply of oil, too little lubrication is provided. The spindle becomes overheated and carbonizes what little oil it gets. In either case the exhaust-valve spindle will be inclined to "stick."

LARGE HORIZONTAL GAS ENGINES

Large gas engines are used for driving electric generators in iron- and steelworks, in collieries, occasionally in large central power stations, and, in rare instances, in textile mills.

Large two-stroke cycle gas engines are also extensively used in ironworks to drive blowing engines which produce compressed air for the blast furnaces.

All large gas engines are double acting; most of them are of the four-stroke cycle type, built usually as tandem-cylinder engines, rarely with one cylinder only. The largest power units consist of two tandem engines placed side by side—a twin-tandem engine—operating an electric generator mounted between them on the main shaft. Two-stroke cycle gas engines have only one cylinder and operate at a lower speed than four-stroke cycle engines.

Large Gas Engines

Classification	Number of cylinders	Horsepower per cylinder	R.p.m.
Four-stroke cycle double acting........	1 to 4	300 to 1,500	$^{150}/_{90}$
Two-stroke cycle double acting.........	1	400 to 2,000	$^{100}/_{60}$

Methods of Lubrication

Internal Lubrication.—The cylinder, stuffing boxes and exhaust valve spindles are always lubricated by means of a mechanically operated lubricator delivering the oil under pressure to the various parts and operated from the camshaft.

Cylinder.—The oil is introduced into the cylinder at three to six points, through ¼-in. copper pipes from the mechanically operated lubricator. The oil inlets are sometimes located at the middle of the cylinder of four-stroke cycle engines, but in the case of two-stroke cycle engines this is not possible on account of the exhaust belt around the middle of the cylinder. In this case the oil inlets are placed about halfway between the exhaust belt and the cylinder ends.

It is important that the oil be introduced into the cylinder at the moment when it will be fed directly to the piston and the

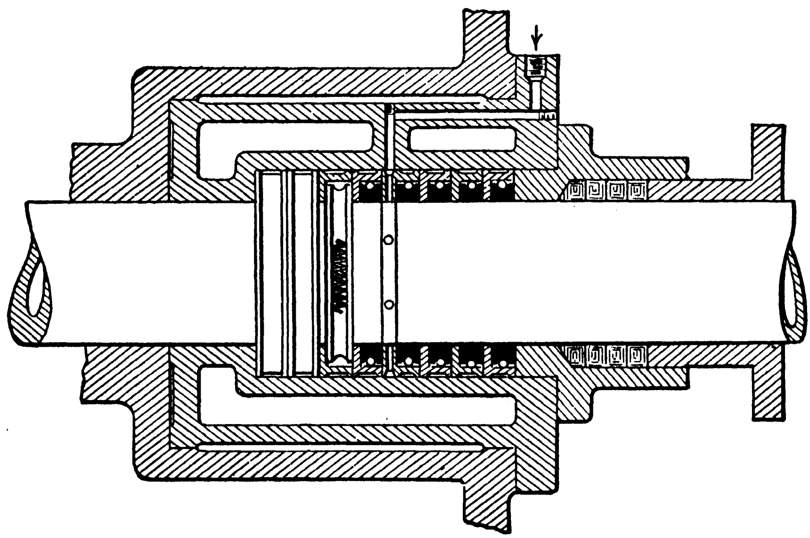


FIG. 173.—Stuffing box for large gas engine.

piston rings. If introduced when the oil inlets are uncovered, it is burned by the hot gases, resulting in waste of oil and the formation of deposits.

Stuffing Boxes.—The stuffing boxes located in the cylinder heads are the parts that usually give the most trouble. The oil is introduced under pressure into the middle of the stuffing box and distributed over the entire frictional surfaces of the packing rings (see Fig. 173). These are usually cast-iron rings made in two halves and held together around the piston rod by means of light garter springs. Outside the packing rings there is occasionally a second stuffing box, employing soft packing.

Exhaust-valve Spindles.—Although the exhaust-valve guides surrounding the exhaust-valve spindles are water cooled, it

becomes necessary to lubricate the spindles with a uniform and very sparing supply of oil for the same reasons as mentioned under medium-size gas engines.

Mixing and Inlet Valves.—The mixing- and inlet-valve spindles are sparingly hand oiled, except in very large engines, where they are supplied with oil through separate feeds from the mechanically operated lubricator.

Gas and Air Pumps.—As the gas and air are sucked into these pumps at a slight vacuum and delivered from the pumps to the working cylinders at a pressure of 4 to 6 lb., the temperature of the pump-cylinder walls, owing to compression, is not much above 100°F. There is, therefore, no need for water-jacketing these cylinders, and their lubrication presents no difficulties where the gas and air are clean.

The practice has been to feed the oil through sight-feed drop oilers into the center of each pump cylinder, with additional oil feeds to either end of both gas- and air-valve chambers. Frequently, however, an accumulation of deposits has been experienced due to moist dirty gas and overfeeding of the oil, the impurities adhering to the excess oil. Under these conditions it has been found better practice not to lubricate the pump cylinder and valve direct but to introduce the oil uniformly and sparingly, by means of a mechanically operated lubricator, through atomizers in the respective intake pipes.

External Lubrication. *Circulation System.*—In the external lubrication of large gas engines a circulation system is usually employed. The lubrication of main bearings, crankpin, crosshead, tail-rod support, and guides is accomplished by means of oil fed by gravity from a top supply tank through a distributing pipe and its branches, into the various bearings. Adjusting valves are fitted in the branch pipes to regulate the oil feeds. Having done its work, the oil drains back to the bottom receiving tank.

An oil pump driven by the engine draws the oil from the receiving tank and delivers it through an oil cooler into the top tank. If more oil is delivered to the top tank than is required for the bearings, the surplus oil overflows through an overflow pipe back into the receiving tank. The top tank may be omitted, and the oil passed directly from the oil cooler into the distributing pipes in which case it becomes necessary to have a relief valve, through which the surplus oil is passed back into the bottom tank.

The oil is delivered to the crankpin through the hollow crankshaft, and in order to distribute it well there are usually three or four radial holes (120 deg. apart) through which it reaches the large bearing surface.

The oil for the crosshead bearings is delivered to the crosshead guide. The crosshead shoe is so long that the oil hole in the guide is never uncovered; consequently, the oil is enabled to force its way through drilled passages in the crosshead, as indicated in Fig. 174.

To give an idea of the dimensions of bearings and oiling system, the following two examples are cited as typical of existing engines:

Circulation System for 1,000-B.Hp. Two-stroke Cycle Single-cylinder Gas Engine

Engine speed	94 r.p.m.
Quantity of oil in circulation	40 gal.
Type and size of pump	Plunger pump, 1½ in. diameter by 1½ in. stroke
Speed of oil pump	94 strokes per minute
Height of oil pump above oil level in bottom tank	4 ft.
Three main bearings	18 in. diameter by 33 in. length
One crankpin	18 in. diameter by 30 in. length
Oil-delivery pipe	1½ in. diameter
Oil-return pipe	2 in. diameter

All waste oil flows direct to the bottom oil tank, which has two vertical strainers, through which the oil passes to the oil pump; the suction pipe is fitted with a strainer and a nonreturn valve (foot valve).

Circulation System for 1,000-B.Hp. Four-stroke Cycle Tandem-cylinder Gas Engine

Engine speed	140 r.p.m.
Quantity of oil in circulation	80 gal.
Type of oil pump	Rotary, 4 in. wheels
Speed of oil pump	140 r.p.m.
Height of pump above oil level in bottom tank	6 ft.
Three main bearings	16 in. diameter by 25.5 in. length
One crankpin	15.5 in. diameter by 19.0 in. length
Two crosshead bearings for forked connecting rod	9 in. diameter by 9.5 in. length
Oil-delivery pipe	2 in. diameter
Oil-return pipe	2 in. diameter

All waste oil is led to a separating tank, which retains most of the water and impurities. The oil then passes through a filter before being delivered to the bottom oil tank through a strainer.

Timing shafts are usually supported by ring-oiled bearings.

Eccentrics are equipped with sight-feed drop oilers or automatic-compression grease cups.

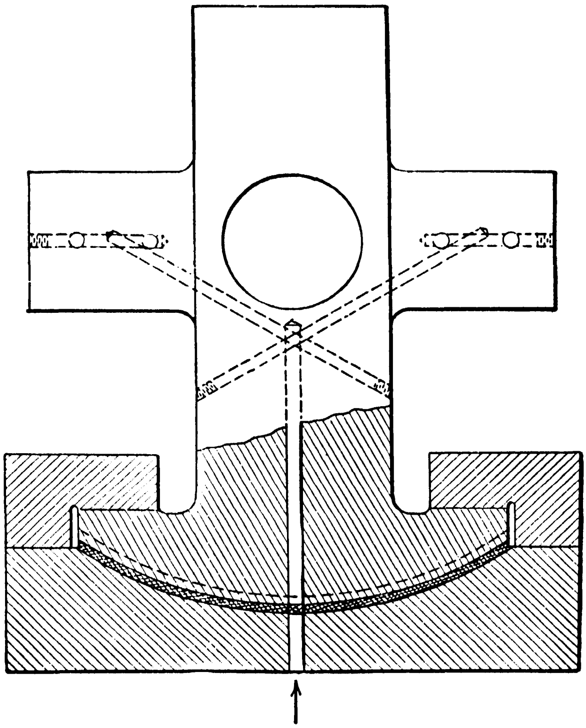


FIG. 174.—Crosshead of large gas engine.

Valve levers are sparingly hand oiled.

Governor.—The governor is oiled partly by sight-feed drop oilers and partly by hand.

VERTICAL GAS ENGINES

Vertical gas engines are used principally for driving electric generators which produce current for lighting or for operating electric motors. They are also used, occasionally, for driving air compressors, large centrifugal pumps, refrigerating plants, etc.

Practically all vertical gas engines are of the four-stroke cycle types.

Some large two-stroke cycle vertical gas engines have been developed in England but may be said to be still in the experimental stage.

Type	Number of cylinders	Horse-power per cylinder	Revolutions per minute
Four-stroke cycle:			
Multiple cylinder	1 to 6	5 to 125	$^{350}/_{225}$
Multiple tandem cylinder	4 to 12	5 to 125	$^{350}/_{225}$
Two-stroke cycle:			
Double acting, with oil or water-cooled pistons	2 to 4	200 to 500	$^{160}/_{140}$

Constructional Points.—There are two types of vertical four-stroke cycle gas engines: the multiple cylinder type and the multiple tandem-cylinder type (shown diagrammatically, Fig. 175). Vertical engines are rarely built with one cylinder only; they generally have three or four. The multiple tandem-cylinder type usually has four or six pairs of cylinders, *i.e.*, 8 or 12 cylinders, and is developed only in England: by the British Westinghouse Company and by the National Gas Engine Company.

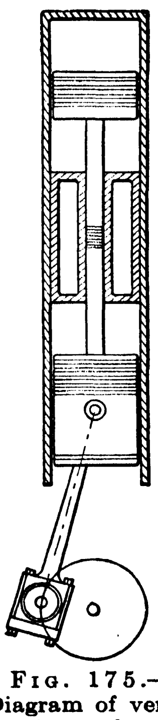


FIG. 175.—Diagram of vertical tandem-type gas engine.

As vertical gas engines are always enclosed, and the cylinder walls copiously supplied with oil, the pistons are frequently designed with oil scrapers at the bottom in connection with grooves from which the oil can be drained through holes to the interior of the piston and thence down into the crank chamber. Also, it is good practice to design the pistons in two parts, inserting between the top and bottom portion a plate, which prevents the oil from the gudgeon pin from splashing into the hot hollow piston head, where it would otherwise burn and char. As an alternative the piston may be cast with a projecting internal lip above the gudgeon pin, the hole being closed by a plate.

In the case of the vertical tandem-type gas engines, the two pistons are connected by means of a piston rod working in a

sleeve between the two cylinders. The air below the top piston is compressed on the downstroke and acts like an air buffer.

Methods of Lubrication.—Vertical four-stroke cycle gas engines operate at high speed. In order to prevent the lubricating oil from splashing away from the bearings, all external-motion parts are enclosed in a crank chamber or casing, so that the parts may be copiously supplied with oil, either by the splash system of ubrication or by the force-feed circulation system.

CRANK-CHAMBER LUBRICATION

Splash Oiling System (Fig. 176).—The lower portion of the crank chamber is filled with oil to the level indicated in the drawing, and an adjustable overflow pipe is fitted to one end of the crank chamber in order to maintain a correct oil level. The bottom ends of the connecting rods dip into the oil and splash it to all parts requiring lubrication.

Oil is fed into the outer main bearings by sight-feed drop oilers. Leaving these bearings it drops into the crank chamber and thus makes up for the amount of oil that goes away as oil spray or is burned away inside the cylinders. In place of sight-feed drop oilers, a mechanically operated lubricator is preferably employed to supply oil uniformly to the main bearings, in this way making the lubrication system entirely self-contained and automatic in action.

A correct constant oil level must be maintained, in order to secure uniform splash to all parts and to obtain greatest economy. Connecting rods should dip into the oil to the same depth, and the oil level should be lowered until the formation of carbon deposits on the pistons is reduced to a minimum.

An irregular or *too high oil level* means waste of oil and excessive carbonization. *Too low an oil level* or the use of *an oil too heavy in viscosity* means unequal distribution and insufficient lubrication for some of the parts, resulting in excessive wear of those parts. It cannot be too strongly emphasized that an adjustable overflow should be installed, in order that the correct oil level, once established, may be automatically maintained.

Force-feed Circulation System.—This system delivers the oil under a pressure of from 5 to 20 lb. per square inch to all bearings, the oil leaving the gudgeon pins splashing on to the cylinder walls. The circulating oil sometimes passes a filter or a cooler.

Oxidation.—In passing through the main bearings, crankpin bearings, and wrist-pin bearings, the oil is subjected to high temperature and speed of the rubbing surfaces. Oxidation takes

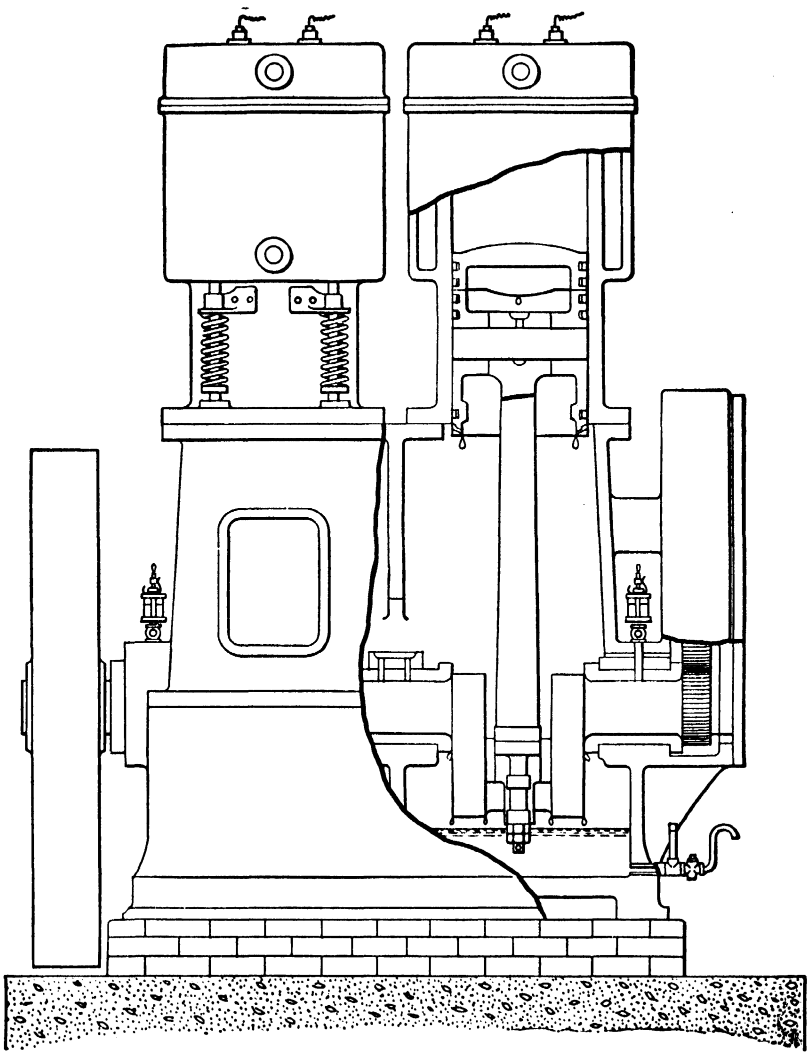


FIG. 176.—Splash-oiled vertical gas engine.

place and is indicated by a darkening in color, an increase in viscosity and gravity, and the development of acidity.

Temperature.—As the crank chamber is enclosed, the heat radiated from the pistons and cylinder walls is, to a large degree, retained, so that the oil in the crank chamber gets warm, reaching a temperature of from 100 to 160°F. If a temperature of 140°F. is greatly exceeded, the life of the oil will be shortened, and it may

throw down a dark deposit caused by oxidation similar to that which may take place with turbine oil.

The force-feed circulation system is always employed in vertical, four-stroke cycle, multiple tandem-cylinder gas engines and is superior to the splash lubricating system. The splash system is used in some multiple-cylinder engines, but the majority of these engines employ the force-feed circulation system.

It is a common trouble that oil in the crank chamber becomes contaminated with carbonized matter working down from the pistons. In order to prevent dirty oil from the trunk pistons from dropping into the crank chamber, some builders of vertical two-stroke cycle gas engines and vertical multiple-cylinder four-stroke cycle engines raise the cylinders above the crank chamber by means of a distance piece. The piston rods pass through scraper glands and are connected inside the crank chamber to crossheads.

By this construction carbonized matter can be prevented from entering the crank chamber, but as the pistons are not lubricated by splash from the crank chamber, it becomes necessary to lubricate them independently, by means of a multiple-feed mechanically operated lubricator. This practice permits the use of a different oil for piston lubrication, which is often desirable.

As burned gases occasionally escape past the pistons into the crank chamber, this is provided with an air-vent pipe, frequently fitted with a fan, which sucks away from the enclosed crank chamber fumes and vaporized oil. At the same time, cold air is constantly drawn through the engine and helps to cool the pistons and crank chamber.

As regards the piston lubrication, one oil feed from the lubricator goes to each piston, delivering the oil through a check valve into an annular oil tube surrounding the cylinder, from which two, four, or six leads go through the water jacket and distribute the oil over the piston surface. As the oil is introduced at one point of the annular oil tube, it is likely to pass into the cylinder through the leads nearest this point, so that the opposite side of the cylinder may get little or no oil direct from the leads. For this reason it is good practice to have each point of entrance to the cylinder fed by a separate oil pump, so that each feed can be controlled with certainty. Two oil feeds suffice up to 21-in. cylinders, one for the front and one for the back of each piston.

Furthermore, the oil should preferably be introduced in line with the level between the first and second piston ring, when the piston is in its lowest position. The oil feeds from the mechanically operated lubricator should be capable of independent adjustment, so that the exact amount of oil required can be supplied to the sleeves and pistons.

Pistons.—The piston rings should be in good condition and pegged, so that only a sufficient amount of oil for full lubrication will reach the entire piston surfaces. Too much oil splashed from the crank chamber (too high oil level, too high oil pressure) or too much fed directly to the piston means that excess oil will pass to the piston tops, where it will burn and char and ultimately form deposits.

In the case of multiple tandem-cylinder engines, care should be taken that the quantity of oil fed from the mechanically operated lubricator to the top pistons and the sleeves be reduced to the exact amount required. This applies also to multiple-cylinder engines with a distance piece between the cylinders and the crank chamber.

COOLING OF GAS ENGINES

Cooling of all parts of the engine that come in contact with the hot gases is necessary. Without adequate cooling, unequal expansion and distortion of the overheated parts, excessive wear, and piston seizure would occur.

Small gas engines employ the thermosiphon system, but most medium-size and all large gas engines employ pump circulation. In large gas engines, provision is made for adjusting the supply of cooling water to the various parts (cylinder walls, piston, piston rods, cylinder covers, and exhaust valves). All return-water pipes are carried to a central place, where the temperature and the quantity of cooling water from each part can be controlled. The cooling water, after its return from the various parts, is pumped through a cooling tower, cooled, and again pumped through the engine.

Smaller engines employ cooling tanks, which must be so arranged that the water from one tank flows into the bottom of the next one (Fig. 177*A*). With the arrangement shown in Fig. 177*B* the water flow is short-circuited, and the water is not properly cooled.

In the inlet and outlet pipes should be fitted thermometers for registering the temperature of the cooling water. The average temperature of the return cooling water should be between 100 and 130°F. in large gas engines and between 100 and 140°F. for smaller ones. If the outlet water from the water jacket is too high, the temperature of the cylinder wall will rise; the oil film thins out, losing its sealing power; and the explosion gases blow past the piston. If the outlet water is much below 100°F., the cooling of the cylinder wall is too efficient. The oil film becomes sluggish, the oil spreads with difficulty, and a great deal of power is lost in overcoming the oil drag on the piston. A tem-

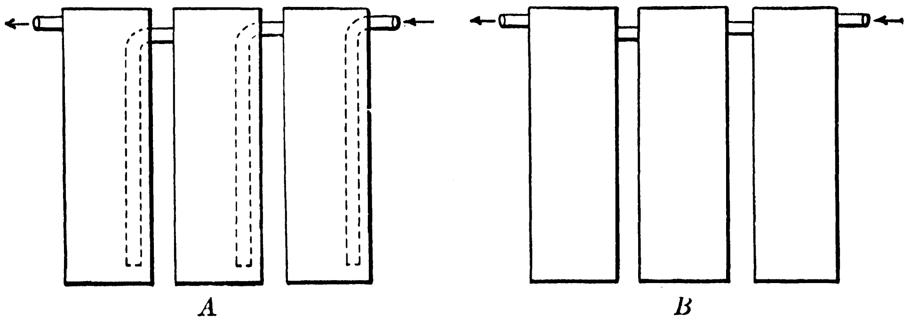


FIG. 177.—Cooling tanks.

perature of 115 to 120°F. is therefore preferable in order to ensure good piston seal and a free sliding motion of the piston.

The cooling water must be clean, for, if impurities settle in the water jacket, the cooling of the cylinder walls and pistons (where pistons are water cooled) becomes defective; the temperature rises; and preignition, caused by incandescent deposits inside the combustion chamber, is likely to occur.

Where the gas contains an excessive amount of sulphur (large gas engines), successful results have been obtained by allowing the cooling water to run through the engine at a higher temperature—as high as 160°F. The higher temperature of the cooling water minimizes, or entirely prevents, the condensation of moisture from the expanding gases and thereby the formation of sulphurous acid, which would attack the internal surfaces of the engine that come in contact with the gases.

GAS

When using rich, highly inflammable gas, such as natural gas, the compression pressure at the end of the compression

stroke must be proportionately low; otherwise, preignition will occur, due to the heat developed by compression. With weak, less inflammable gas, such as the producer gases, the compression pressure can be made much higher.

This is shown in the table below, which gives average comparative heat values of gases and corresponding average compression pressures.

Kind of gas	Heat value, B.t.u.	Compression pressures, pounds per square inch
Natural gas	1000	100
Illuminating gas	600	120
Coke-oven gas	520	130
Producer gases	130	150
Blast-furnace gas	100	190

Small and medium-size gas engines are operated by natural gas; illuminating, or town gas; suction producer gas; or pressure producer gas. Large gas engines are operated by blast-furnace gas, coke-oven gas, or pressure producer gas.

Natural Gas.—Natural gas is found in the oil districts of the United States, Canada, Russia, and Mexico. It is dry in its natural state, with a degree of purity that makes cleaning unnecessary.

Illuminating, or Town, Gas.—Illuminating gas is used practically only for small gas engines. It is made from bituminous coal by dry distillation. It is free from impurities and is, therefore, an excellent fuel.

Suction Producer Gas.—Suction producer gas is usually made from coke, anthracite coal, lignite, wood refuse, etc. The engine draws the gas from the producer by suction—hence the name *suction* producer gas. Suction producer gas plants are used for installations comprising one or more engines with a total power not exceeding 500 hp.

Pressure Producer Gas.—Pressure producer gas is made from a variety of fuels, such as bituminous coal, lignite, coke, anthracite, charcoal, sawdust, and wood refuse. It is produced under slight pressure—hence the name *pressure* producer gas.

Pressure producer-gas plants are sometimes used for installations as small in size as 200 hp., but the installations usually range from 400 to 2,000 hp. or more, employing medium- or large-size gas engines.

Where bituminous coal is used, rich in tarry matters, the cleaning plant for the gas must be more elaborate and efficient and therefore more costly than in the case of suction producer-gas plants, which preferably use fuel free from tar.

Producer gas, whether suction gas or pressure gas, should be thoroughly scrubbed, cooled, and cleaned; but, notwithstanding all precautions taken, the gas always contains, besides moisture, more or less impurities, such as soot, fine dust (coke dust, ash), and tar, which are carried into the engine and interfere with lubrication.

Blast-furnace Gas.—The blast-furnace gas coming from the blast furnace contains a great quantity of impurities, consisting of lime dust, fine iron oxide, coke dust and volatile matter from incomplete combustion in the blast furnace, water impurities from the water used in washing the gas, and a small amount of sulphur. The quantity of impurities varies from 12 to 25 g. per cubic meter of gas and is reduced in the cleaning plant to 0.01 to 0.03 g. per cubic meter. If the impurities are more than 0.05 g. per cubic meter, the gas is dangerous for the engines and will cause deposits and excessive wear of piston rings and cylinder walls.

The gas is freed from the dust and tarry impurities by either the wet- or the dry-cleaning process. By the latter it is filtered dry through filter bags and is delivered in a less moist condition to the engines, so that it is less liable to deposit dust in the mixing valves and cylinders.

Coke-oven Gas.—Coke-oven gas is produced from bituminous coal during the production of coke. A portion of the gas is used in the coke oven, but the surplus can be used for operating gas engines. The coke-oven gas contains, besides coke dust, tar and sulphur.

Sulphur in Coke-oven or Producer Gas.—Heavy wear is often noticed when the gas is not sufficiently low in sulphur content. The wear is chiefly on the piston rod but only on the part rubbing in contact with the rings in the metallic packing. The greatest wear is where the rod is coolest, *i.e.*, where the water enters; the

wear is less on the tail rod, where the water leaves the rod warm. The rod does not get pitted but wears uniformly, maintaining a bright polished surface, with dark-colored patches showing here and there.

By allowing the cooling water to pass warmer through the rods, the wear, as mentioned on page 477, is reduced or eliminated.

If a piston rod gets splashed with water from the water-discharge tubes (outside the cylinder), it will wear rapidly, if the gas contains an excessive amount of sulphur. A water leak from the cylinder head into the metallic packing will have a similar effect. In the case of a porous cylinder, allowing cooling water to leak into the cylinder, sulphur will cause extremely rapid wear.

DEPOSITS

Deposits form in the mixing and inlet valves, in the cylinders, on the piston, behind and between the piston rings, on the exhaust valves, and in the stuffing boxes. In two-stroke cycle engines deposits are also formed in the gas and air pumps. Deposits may arise from one or several of the following causes: dust or dirt in the intake air, incomplete combustion, impurities in the gas, overfeeding of oil, the use of an unsuitable oil. The formation of deposits under certain conditions leads to preignition and backfiring.

Intake air is usually not filtered, even when the engines are placed in dirty surroundings. Impure intake air is therefore a frequent cause of deposits in gas engines, regardless of the kind of gas used (see Examples 33, 36, and 38, pages 483, 484, 486). In such cases a chemical examination will prove the presence or sand, brick dust, lime dust, etc. The deposit will also contain oil and partly decomposed oil, owing to the oxidizing action of the impurities on the oil under high-temperature conditions, and there will always be present a percentage of iron and iron oxide, due to wear of the piston rings and cylinder.

In large gas engines the air should be filtered through coarse canvas or similar material before passing to a large settling chamber, which will collect more of the solid impurities.

Incomplete combustion will bring about sooty crumbly deposits and may be due to poor ignition or improper timing of the valves.

Impurities in the Gas.—(See Examples 36, 37, and 38.)

Where *producer gas* is in use, deposits may be caused by such impurities as ash, fine coke dust, free soot, or tar passing into the engine. All fuels contain ash, and a regular feeding of fuel through the generator and removal of clinker from the grates are very desirable, because, if the grate is not covered with a sufficient layer of fuel, fine ash is likely to be carried over with the gas. Regular firing is therefore important, as it prevents the layer of fuel from getting too low.

Where coke is used, there is no tar, but coke dust may be carried over in such fine form that the water trap, scrubber, and filter will not remove it.

Where gas is produced from anthracite coal, tar and soot may both be carried over, although anthracite contains only a small percentage of tar.

Where gas is produced from lignite, which contains more tar and soot, the danger of forming deposits inside the engine is more pronounced.

Lignite also contains a small percentage of sulphur; this, in many cases, will cause a blackening of the piston surface but rarely causes serious trouble.

Where gas is produced from bituminous coal, which contains a large percentage of tar, there is greatly increased likelihood of the gas's carrying soot and tar into the engine.

Coke-oven gas and pressure producer gas contain some volatilized tar which cannot be eliminated in the producer plant and settles in the gas-inlet valve and mixing chamber or in the gas pump (two-stroke engines). When inlet valves stick, they can be "freed" by applying creosote. The tar affects the lubrication, encouraging the formation of carbonaceous deposits. It is this formation of tar that makes it necessary in suction producer plants to employ coke or noncaking anthracite coal.

The moisture in wet gas, such as the producer gases and blast-furnace gas, forms a paste with the impurities in the air or gas, thus providing a base for the ready formation of deposits. The impurities collect in the mixing and inlet valves and on the internal surfaces of the engine exposed to the gas, adhering to and contaminating the oil film on the piston, piston rings, and cylinder walls. The pasty deposits in the mixing-valve chambers in time become crumbly, peel off, and are swept into the cylinders, causing excessive wear, preignition, etc.

In two-stroke cycle gas engines, moist gas will also deposit the dust, in the form of a dark sludge, in the valve chamber of the gas pump. The sludge causes increased resistance in moving this valve, with consequent sluggish action of the governor.

Deposits arising from air or gas, or both, always contain oil and also partly decomposed oil, the latter due to action of the impurities on the oil under high-temperature conditions.

Overfeeding of Oil.—The surplus oil, fed to the internal parts, burns and chars; it also attracts and collects the impurities from the gas and air, resulting in a dark-colored carbonaceous deposit of a harder or softer nature, depending upon the nature of the oil in use. Even with a good-quality oil in use, the oil feeds should be reduced to the exact amount required for full and efficient lubrication. This will lead to cleaner lubrication, as the impurities find less oil to which they can adhere.

Deposits accumulating behind the piston rings may cement the rings in their grooves, so that they lose their elasticity and break easily. Heavy wear takes place; the oil film is burned away; the burning gases pass the piston, and, in the case of double-acting engines, pass from one side of the piston to the other, igniting the fuel charge on the opposite side and causing preignition. Increased oil feed will only aggravate the trouble. Frequently, the stuffing boxes in large gas engines are overlubricated, with the result that carbon deposits are formed, causing the packing rings to stick in their grooves. Wear follows, and the gases blow past the rings.

Preignition.—When carbon or other deposits develop inside the combustion chamber, and particularly if the water cooling is inefficient, the deposits often become incandescent and preignitions occur, causing abnormally heavy strains on the engine.

But deposits are not the only cause of preignition. Jointing material—asbestos, red lead—is often the cause of this trouble. Preignition may also be due to the use of rich gas, *e.g.*, town gas in engines designed for suction gas, as the richer gas ignites spontaneously at a lower temperature.

With blast-furnace gas it is difficult to prevent preignition, owing to the quantity of fine lime dust in the gas, which, when it settles inside the cylinders, easily becomes incandescent.

In large engines preignitions occur every 2 to 3 hr. under the most favorable conditions and, under unfavorable conditions, every few revolutions.

Preignitions may be caused by the explosion gases leaking past the piston rings from one side of the piston to the other. This happens when the rings are badly sealed, owing either to accumulated deposits causing the rings to be inflexible in their grooves, or to the use of too low viscosity lubricating oil, or to a furred up water jacket (the oil film gets hot and thins out), etc.

A FEW EXPERIENCES

Example 33. *Dirty Intake Air.*—The following analysis of two deposits taken simultaneously from the piston indicates dirty intake air, which has caused a great deal of wear (iron oxide). The hard deposit at one time has no doubt passed through the stage represented by the soft deposit, the oil gradually charring and hardening the mass. The oil in use was a straight mineral paraffin-base oil; had it been an asphaltic-base oil, and preferably compounded, the deposit would not have hardened, but would have been in the form of a crumbly or greasy paste.

Components of deposit	Deposit, per cent	
	Soft	Hard
Oil	34.9 } 68	12.1 } 66.4
Volatile matter insoluble in petroleum spirits	33.1 }	54.3 }
Iron oxide	28.0	30.4
Silica	1.6	1.2
Balance undetermined	2.4	2.0
	100.0	100.0

It is surprising many times to see the lack of care in not providing gas engines with reasonably clean intake air.

Example 34. *A Curious Case of Spontaneous Ignition.*—An old gas engine of about 25 hp., with leaky piston rings and with a temperature of about 200°F. in the water jacket, was using a heavily compounded oil. The gudgeon pin and piston were very hot. The engine was in a wooden shed close to saw benches, and, as the door of the shed was always open, a considerable amount of wood dust was always entering the engine room. In particular where the crankpin had thrown the oil on the side of the shed, the dust and oil had formed a layer a ¼ in. thick. One day the heat of the piston caused the oil to ignite, throwing out a

flame sufficiently long to reach the layer of oil on the side of the shed, which it also ignited.

The ignition took place in the hollow part of the piston where the gudgeon pin end of the connecting rod works. The sawdust had accumulated in the hollow of the piston and was saturated with the highly compounded oil in use. As time went on, this oil became gummy, oxidizing more and more; and as the heat from the piston increased, owing to the gas engine's being heavily loaded, the oxidizing effect raised the temperature up to ignition point.

Example 35. *Bad Alignment.*—A 60-hp. gas engine was continuallyb reaking piston rings; the back piston ring could not be lubricated, and the piston could therefore never be kept tight. The makers had overhauled the engine time and time again without locating the cause; a special attachment was fitted which lubricated the back ring, but the breakages continued. Finally, the seat of the trouble was discovered; the cylinder was out of line with the crankpin to the extent of 3⁄16 in., which caused a great pressure between the piston rings and the liner.

Example 36. *Deposit Caused by Impurities in the Gas.*—Several large blast-furnace gas engines of the Cockerill type (double-acting, four-stroke, tandem engines, 1,500 hp.) were wearing badly owing to deposits which continued to develop

Components of deposit	Piston surface outside the rings, %	Piston surface between the rings, %	Inside of piston rings, %	Piston rod, %
Oil and moisture	Traces	Traces	Traces	Traces
Volatile matter insoluble in petroleum spirit	34.9	43.3	37.8	56.9
Silicates and silica	16.6	12.1	17.7	12.5
Iron oxide	18.3	22.4	11.2	10.8
Aluminum oxide	5.7	.....	.....	6.4
Calcium oxide	12.6	22.2	33.3	10.2
Balance, containing magnesium oxide and traces of other metallic salts	11.9	.....	.....	3.2
	100.0	100.0	100.0	100.0

inside the cylinders. The cylinder wear had averaged 0.7 mm. per annum, as compared with the normal wear for large blast-furnace gas engines, which ranges from 0.3 to 0.5 mm. per annum.

Samples of deposit were obtained from the points shown in the table on page 484 and analyzed.

All the deposits were hard, granular, and black, and their composition shows that the gas is mainly responsible for their formation, the dust contents in the gas ranging from 0.025 to 0.035 g. per cubic meter. The lubricating oil in use was a deep-red straight mineral paraffin-base oil containing filtered cylinder stock which carbonized and cause the deposit to bake into hard

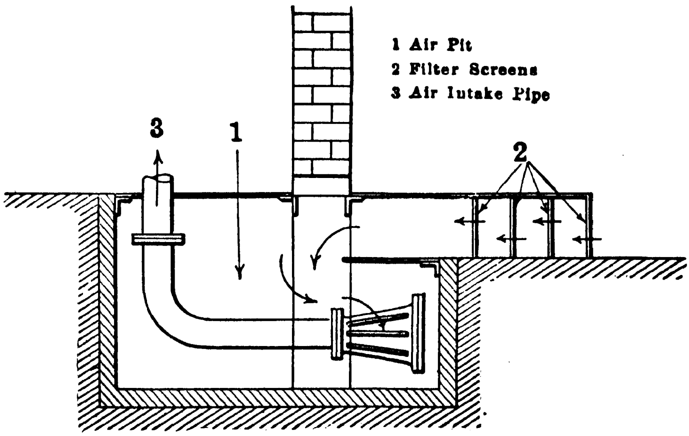


FIG. 178.—Filtering intake air.

crusts. It is possible that some of the dust came with the intake air, as the intake-air pipes were placed with their ends turned up, so that the dirt and dust had free access. Besides, on this particular side of the powerhouse were situated the stores of coal, coke, etc. It would have been better had the air pipes been placed on the opposite side of the powerhouse, taking the air through large settling chambers, fitted with suitable filter screens.

Figure 178 shows a good arrangement for preventing impurities from entering a gas engine with the intake air.

Example 37. *Tarry Deposits.*—Two-stroke gas engines employing coke-oven gas are often troubled with tarry deposits, which accumulate in the gas pumps, on the inlet valves, and inside the cylinders.

A 500-hp. Koerting engine had to be dismantled every 4 weeks to clean away the deposits. A straight mineral dark-red paraffin-

base oil was used, fed through sight-feed drop oilers. A mechanically operated lubricator was installed in order to bring about a regular feed, so that a minimum oil consumption could be established. At the same time an oil made chiefly from asphaltic-base mineral oil and compounded with 7 per cent of nut oil was introduced with most remarkable results, it being found possible to operate the engine for 5 months before the deposit had to be cleaned out. In addition, it was found that the engine now started quite easily on compressed air, whereas with the previous oil it was necessary to "motor" the generator when starting.

Example 38. *Deposit Due to Water Leakage.*—In the case of seven 800-hp. blast-furnace gas engines—single-cylinder engines with open-ended trunk pistons—a dark-brown, almost black, oily deposit was continuously working its way out from the cylinders. A sample showed the following analysis:

	Per Cent
Oil	35.3
Water	8.2
Iron, iron oxide, and silica	21.9
Volatile matter insoluble in petroleum spirit	34.6

The water came from the leaky cooling-pipe connections; the silica came in with the intake air or the gas and caused heavy wear, the action being accentuated in the presence of water.

OIL

General.—The frictional losses in a small or medium-size gas engine range from 15 to 30 per cent; in large gas engines, from 10 to 20 per cent of the rated horsepower, this loss being constant and independent of the actual engine load. It is easy to waste from 5 to 10 per cent of the engine power in unnecessary friction by using unsuitable lubricating oil or an inefficient lubricating system.

Small and Medium-size Horizontal Gas Engines

Piston Lubrication.—The *piston* of the gas engine is the most vital part from a lubricating standpoint. With impure gas or unsuitable oil or overfeeding, deposits develop on the piston head and behind the piston rings and will appear in the form

of a black, oily coating. These deposits soon cause the piston rings to cement in their grooves; the gases blow past the piston; excessive friction and wear take place on the piston rings and on the cylinder walls.

It is important that the oil shall have a suitable viscosity. If an oil of *too heavy viscosity* is used, it does not spread easily over the piston surface. The friction is high owing to the heavy oil drag on the piston, and impurities in the gas or air will cling to the heavy oil and bake into crust-like deposits.

If an oil of *too light viscosity* is used, it will break down under the influence of the high temperature in the cylinder; it will lose its sealing power, causing excessive friction and wear. Carbonaceous deposits are formed which on account of the wear will be found to contain a large percentage of iron and iron oxides.

Bearing Lubrication.—*Main bearings* usually give no trouble; it is bad practice to add oil to ring-oiled main bearings daily. The bearings do not run cooler, but the oil is wasted, overflowing from the bearing ends.

The bearing reservoirs should be emptied, cleaned, and recharged at regular intervals—from 3 to 6 months—depending upon the purity (absence of dust) of the air in the engine room.

The *crankpin* is a very important part of the engine, as it transmits the power from the piston to the main shaft. Occasionally, a heavy-bodied oil is required for lubricating the crankpin of medium-size engines owing to the heavy crankpin bearing pressures. As this oil may be too heavy in body for the cylinder lubrication, two different oils are sometimes used, although usually one is used throughout.

The *gudgeon* or *wrist pin* requires particular care in lubrication, as it is located in the interior of the heated hollow trunk piston, where it is subjected to high temperature. The pressures on the wrist pin are high, and, as the oscillating motion of the connecting rod is slight, the oil spreads with difficulty over the bearing surfaces. Consequently, the lasting and lubricating properties of the oil used are very important.

The blackened waste oil coming from the piston and wrist pin in small and medium-size engines should be arrested by a division plate (see Fig. 171, page 465) and drained away so that it will not run into the crank pit and contaminate the oil coming from the crankpin.

Large Gas Engines

Piston Lubrication.—Owing to the large diameter of the pistons, it is of the greatest importance that the oil be introduced direct to them at several points and in such a manner that the correct amount is delivered at the correct moment, positively and regularly. Incorrect methods of lubrication, or lubricators that cannot be relied upon to feed the oil in the best manner, mean excessive oil consumption; the waste of oil is less important than the fact that the impurities in the gas adhere to the surplus oil, which leads to the formation of carbonaceous deposits.

In the United States practically all large gas engines are lubricated with oils that are highly filtered cylinder stock, having viscosities ranging from 26 to 32 centipoises at 100°C.

The very same types of engines are lubricated successfully in Europe with oils having viscosities ranging from 26 to 76 centipoises at 50°C. It is practically certain that the American engines would operate better, with less friction, easier starting, and less carbon deposit, if they used oils more in line with European practice.

Stuffing-box Lubrication.—When an oil too low in viscosity is used it cannot seal the packing properly and allows gas to blow through the stuffing boxes. The gas burns and chars the oil, causing heavy wear and the formation of deposits. The action of the gas is extremely erosive, cutting grooves in the piston rod and shortening the life of the metallic packing. The gas escaping from the stuffing boxes into the engine room is very poisonous.

It is quite usual to find that the oil is fed to the stuffing boxes by means of sight-feed drop oilers and that, therefore, a great deal more oil is used than when the stuffing boxes are lubricated by means of a mechanically operated lubricator. It is very important that the lubrication of the stuffing boxes should be kept clean and economical. Excessive oil feed means formation of carbon deposit, excessive friction, and wear, accentuated by continuous "blowing" of the glands.

Where the stuffing boxes are worn, and blowing takes place, they should be put in good order at the earliest opportunity, although as a temporary arrangement an oil heavier in body may be used in order to seal the packing and prevent blowing. Satis-

factory operation of the stuffing boxes is perhaps a more difficult problem from a lubricating point of view than that of any other part of the engine; it pays, therefore, to give special attention to selecting the correct oil for their lubrication and applying it in the best manner, using it as economically as possible.

Only *fresh oil* should be used for lubrication of stuffing boxes, pistons, valves, etc. Any *waste oil* that may be collected from underneath the stuffing boxes, valve spindles, etc., may be treated in a heated separating tank and filter, after which it can be used for less important work, but it should not be used on the gas engine itself, as it is usually very dirty.

External Lubrication.—The *circulation system* in large gas engines should preferably contain not less than 100 gal. of oil, in order to give the oil a chance to rest and separate from the impurities that may enter the system. The oil is in constant circulation, exposed to the effect of air and more or less water which leaks in from the cooling system or from the water-cooled main bearings. The action is very similar to what takes place with oil in a steam turbine, only the effect is less marked since the temperatures and speeds are lower than in turbines, and the circulation is less rapid.

Unsuitable oil may throw down deposits of various kinds which are liable to accumulate in the most dangerous places, *viz.*, the oil passages inside the main bearings and crankpin, and may cause dangerous heating of the bearings.

Leakage of water into the oil system is a source of great annoyance and often produces emulsion. The life of the oil is much reduced, and wear of crankpins and crosshead pins is increased. It is almost impossible to keep all water out of the system, but leakage may be largely overcome by careful attention to packing and joints of the cooling-water inlet and outlet pipes.

In view of the unfavorable influence of water in the circulation system, any accumulation of water and impurities should be carefully drained away at frequent intervals. Where a great many impurities enter the system, the oil or part of it should continuously pass through a filter. As an alternative, from 2 to 6 gal. of oil should be removed every day for treatment in a steam-heated separating tank and afterward in a good filter. The purified oil should be returned to the circulation system at the same time that a corresponding quantity of oil is removed

from the system for treatment. When the oil-tank capacity in the system is small, this practice is particularly desirable. In this way the vitality of the oil is kept at as high a standard as possible, and its life is greatly lengthened.

Circulation oils should preferably be used. Such oils under reasonably good conditions of service are practically indestructible, and under adverse conditions (air, water, impurities) they are not so liable as other oils to emulsify or throw down deposits.

VERTICAL GAS ENGINES

Unsuitable oil (easily oxidized) will throw down deposits of various kinds which are liable to accumulate in dangerous places, such as the oil passages inside the main bearings, crankpins, and connecting rods. This may result in reduction of oil feed to some parts of the engine; the bearing surfaces of the parts affected will overheat and may be partially or wholly destroyed.

Owing to the high speed at which vertical gas engines operate, it is of very great importance that the correct oil be used in the crank chamber, which will give continued perfect service, notwithstanding the severe conditions of speed and temperature to which the oil is exposed. Consideration must be given to the temperature of the oil in circulation, as with a high oil temperature it is necessary to use an oil heavy in body.

It must also be kept in mind that the lubrication requirements of the cylinders of a vertical gas engine are different from those of the external moving parts, enclosed in the crank chamber. In larger size vertical gas engines which are constructed with a distance piece between the cylinders and the crank chamber, the lubrication of cylinders and bearings is carried out by means of two separate and distinct systems, *viz.*, mechanically operated lubricator for the cylinders and usually force-feed circulation for the bearings. For bearing lubrication of such engines, circulation oils should preferably be used.

The oil for the cylinders should preferably have noncarbonizing properties and can be chosen entirely with a view to suiting the cylinders.

Where engines have cylinders with trunk pistons mounted directly on top of the crank chamber, and where all parts, including the pistons, are lubricated from a common system

of lubrication, one grade of oil must be used throughout, so that it becomes necessary to select an oil possessing such qualities as will enable it to meet the double requirements of cylinder and bearing lubrication as perfectly as possible.

For *piston cooling* of large vertical engines, cooling oil is preferably used, as it is difficult to guard against leakage, and water would cause emulsification of the oil in the crank chamber.

Circulation oils should preferably be used as cooling oils and should preferably be of light or medium viscosity, as the lower the viscosity the better is the cooling effect; but when joints are leaking a viscous oil may be preferred, as it does not leak so readily and, in mixing with the crank-chamber oil, has less thinning effect on the oil in circulation than a light-viscosity cooling oil.

OIL CONSUMPTION

In all *small or medium-size gas engines*, the oil is frequently fed irregularly, and a great deal is wasted, either because of the lubricators themselves or because it is not possible to give the engines the same close attention and supervision as in large power-plant installations. Frequently, the practice is to use plenty of oil all around the engine and to collect the waste oil and use it, after having filtered it more or less efficiently, for shafting and machinery in the works. This practice is false economy.

Fresh oil only should be used for piston lubrication.

Waste oil from the bearings should be collected, and, if filtered in a good filter, it can be used again on the bearings; good-quality oil can be used over and over again almost indefinitely, producing great economy. If the waste oil, whether filtered or otherwise, is used for the machinery in the plant, the gas-engine attendant feels that he need not use the oil economically, as it is made use of afterward; and the men using the waste oil feel that it is *only* waste oil and in consequence use it extravagantly.

Using the waste oil in the engine room and keeping the gas-engine attendant responsible for his oil consumption ensures the best results; besides, in many cases it will be found that much better results can be obtained on the machinery and shafting in the plant by using, instead of the filtered waste oil, one or several oils, specially selected to suit the various conditions in the plant.

For *small gas engines* up to 50 hp. the oil consumption will range from 2 to 5 g. per brake horsepower-hour.

For *medium-size gas engines* between 100 and 500 brake horsepower the oil consumption will range from 1 to 3 g. per brake horsepower-hour, being lower for the larger engines.

For *vertical gas engines* the consumption ranges from 1.5 to 3.0 grams per brake horsepower-hour, depending largely upon the condition of piston rings, oil pressure, oil level, etc.

For *large gas engines* the oil consumption ranges from 0.6 to 2.0 g. per brake horsepower-hour and averages 1.0 g. per brake horsepower-hour. This consumption is divided among cylinders, piston-rod packings, and bearings, approximately in the ratios of 35, 15, and 50 per cent, respectively.

SELECTION OF OIL

Before selecting the correct grade of oil in order to secure perfect lubrication it is necessary to consider carefully a number of influencing factors, such as the quality of the gas; the piston clearance, number of piston rings, whether pegged or not, whether the whole weight of the piston is supported by external means (large gas engines), or whether the weight of the piston is sliding on the bottom of the cylinder; the temperature of the water jacket; the method of lubrication; also whether there are any mechanical or operating conditions that call for special consideration.

The object of lubrication of gas engines is to provide clean and efficient lubrication of all parts—*clean,* because if the oil film is dirty or blackened with carbonized oil or with impurities from the gas or dirty intake air, good lubrication cannot possibly be expected; *efficient,* meaning not only that lubrication is clean but that the oil is of the correct quality and body to produce as complete a film as possible and reduce the total loss in friction to the minimum.

To show how important it is not to allow mere guesswork to determine the grade of oil to be used, some of the influencing factors mentioned above are commented upon in the following:

The Quality of the Gas.—Illuminating gas and natural gas are always clean and dry, qualities favorable to good lubrication. Occasionally, producer gas, particularly in large installation, may be said to be fairly clean and dry. For engines employing

such gas, straight mineral oils of medium or heavy viscosity *may be used.*

It is probable that most users of producer gas, whether suction or pressure producer gas, whether large or small plants, would always answer the question as to whether the gas was pure, in the affirmative. It is a fact, however, that the gas from practically all producer-gas plants is fairly moist and contains fine impurities, of a tarry and a dusty nature, which in time accumulate inside the gas-engine cylinder, producing carbonaceous deposits.

When the gas contains an excessive amount of impurities or moisture, it will be found that pale-colored compounded oils will show marked superiority over dark-colored straight mineral oils as regards clean lubrication. The fixed oil contains oxygen which burns the carbon, and the result is that the deposits are prevented from caking, and the amount of carbonaceous deposit formed is considerably reduced, whereas straight mineral oils will frequently fail to give satisfaction.

Another advantage of using a compounded oil is the easier starting of the engine. When the engine stops, the piston is hot, and the oil film, when the movement of the piston ceases, is practically squeezed out. Experience proves that the presence of animal or vegetable oil helps to retain a better oil film, which makes starting of the engine easier.

In Germany 15 to 20 per cent of kerosene is frequently mixed with the lubricating oil for the cylinders of large gas engines. The kerosene has a cleansing effect when the gas contains a large amount of impurities.

Piston Clearance.—The larger the engine the greater will be the piston clearance, so that larger size engines require an oil heavier in viscosity than smaller engines, in order to seal the piston completely and prevent blowing. The number and position of the piston rings are also important in this respect, particularly whether they are pegged (which is customary) or otherwise. If the piston rings are few and not pegged, a heavier viscosity oil is required than with a greater number of pegged piston rings, the effect of the pegging being that the rings wear to a fit in the cylinder and are easier to seal.

A heavy viscosity is also required for engines with worn pistons or cylinders. Although it would be better in most cases to

rebore the cylinder and fit a new piston, yet circumstances may make it desirable, at any rate as a temporary arrangement, to use a heavy-viscosity oil until such time as the engine is put in order, when the correct lighter viscosity oil can be used.

Cooling Water.—If the cooling water leaves the cooling-water jacket at a temperature much above 140°F., the cooling of the cylinder walls will be inefficient, and the high temperature will thin the oil, so that this condition may demand an oil of heavy body. In the same way, if the cooling water leaves the engine at too low a temperature, say below 90°F., this condition may demand the use of an oil of light body.

Water cooling of large pistons means that smaller piston clearances can be employed and therefore favors the use of lower viscosity oils. This is the reason why large gas engines can be so satisfactorily lubricated with medium-viscosity oils.

The piston friction is much influenced by the temperature of the water jacket. Gas engines when running light should therefore preferably operate with hot cooling water, or, if this condition is permanent, a *lighter viscosity oil* will have the same effect with normal water temperature, as regards bringing about low friction losses.

Method of Lubrication.—When, owing to the method of lubrication or other reasons, the oil consumption for internal lubrication is high, say more than 1.5 g. per brake horsepower-hour, particular attention must be given to selecting an oil with noncarbonizing properties. When the oil consumption is low, this point is of less importance.

All distilled lubricating oils produce less carbon than undistilled oils—cylinder stocks—and filtered cylinder oils produce less carbon than dark cylinder oils. Heavy-viscosity gas-engine oils should therefore contain little or no cylinder stock, if noncarbonizing qualities are required. If cylinder stock is required to give the desired high viscosity, the distilled oil used for blending should be as viscous as possible in order to reduce the amount of cylinder stock required.

In *medium-size gas engines* the tendency is toward using separate oils for internal and external lubrication, as the bearing requirements call for oils which will stand great pressure and give a good cushioning effect in the crankpin bearings. Such oils are preferably mixtures containing filtered cylinder stock, whereas

GRADES OF OIL FOR GAS ENGINES

Grade of gas engine oil	Viscosity number*	Viscosity, centipoises
1 or 1*c*	6	20 (at 50°C.)
2 or 2*c*	7	26 (at 50°C.)
3 or 3*c*	8	38 (at 50°C.)
4 or 4*c*	11	14 (at 100°C.)

* See table, p. 57.

LUBRICATION CHART FOR HORIZONTAL GAS ENGINES

Type and size of horizontal gas engines	Grades of gas-engine oil recommended — Quality of gas: Dry and clean	Moist and impure
Internal:		
Small size	1 or 2	1c or 2c
Medium size:		
Up to 80 hp. per cylinder,* piston not water cooled	2	2c
80 to 150 hp. per cylinder, piston not water cooled	3	3c
With worn cylinders, or very hot water jacket	3 or 4	3c or 4c
Large size:		
Internal:		
4-stroke cycle, 300 to 750 hp. per cylinder	2	2c
For stuffing boxes only, if not sealed properly by 2 or 2c	3 or 4	3c or 4c
4-stroke cycle, 750 to 1,500 hp. per cylinder	3 or 4	3c or 4c
2-stroke cycle, all sizes	3 or 4	3c or 4c
For gas and air pumps only	2c or 3c	2c or 3c
External:		
Small size	1 or 2	1c or 2c
Medium size:		
Oils 2, 3, or 4 or bearing oils of similar viscosities *i.e.*, bearing oils 4, 5, and 6†	2, 3, or 4	2, 3, or 4
Large size	‡ Circulation oil 2 or 3	

* The dividing line with small piston clearances may be as high as 120 hp., with large piston clearances as low as 50 hp. per cylinder. Oils 3 and 3c to be used above the dividing line; oils 2 and 2c, below the line.

† See page 135.

‡ See page 243.

LUBRICATION CHART
For Vertical Gas Engines

Type and size of vertical gas engines	Grades of gas-engine oil recommended — Quality of gas: Dry and clean	Moist and impure
Small size:		
Up to 50 hp. per cylinder, cylinders and bearings	2 or 2c	2c
Large size:		
Above 50 hp. per cylinder.		
For *bearings only*, crank chamber separated from cylinders by a distance piece		
Oil temperature above 120°F	3 or 4	3 or 4
Below 120°F	2 or 3	2 or 3
For *cylinders only*, oil fed separately to pistons by a mechanically operated lubricator	2 or 2c	2c
For *cylinders and bearings*, pistons lubricated from crank chamber	3 or 4	3c or 4c
For *piston cooling:*		
Cooling system separate from lubricating system	* Circulation oil 1	
But joints leaking badly	* Circulation oil 2.	

* See p. 243.

for internal lubrication the minimum of filtered cylinder stock is desirable, as above mentioned.

The main bearings, being ring oiled, are of course best served by a pure mineral oil. Straight mineral oils are required for large gas engines externally, preferably circulation oils in order to avoid as much as possible trouble from emulsification.

In vertical gas engines, where no water gets into the crank chamber, circulation oils are not absolutely needed; the oils may be chosen chiefly with a view to suiting the piston conditions, and of course the crank chamber temperatures.

For splash lubrication the oil must not be too viscous, as it will then only splash and distribute itself with difficulty.

When compounded oils are used in enclosed vertical gas engines, the compound must be a sweet, nongumming oil, either nut oil or high-quality lard oil made from corn-fed pigs; lard

oil from distillery-fed pigs oxidizes and gums, even if it is free from acid.

In the table on page 495 are given viscosity figures for four gas-engine oils, which may be either straight mineral or compounded with from 6 to 10 per cent of fixed oil; in the latter case a *c* is added to the number of the oil. The specifications for circulation oils 1, 2, and 3 will be found on page 243.

The lubrication charts, pages, 495 and 496, give general recommendations for oils suitable for the main types of gas engines.

CHAPTER XXIX

GASOLINE ENGINES

Gasoline engines are now employed for a great many purposes, such as:

Stationary engines.
Automobiles.
Motorboats.
Motorcycles.
Airplanes and dirigible airships.
Agricultural tractors.

As the design and lubrication of motorboat and stationary engines are similar to those of automobile engines, the lubrication of the former is not specially dealt with.

Agricultural tractors are mostly run on kerosene, but their design and lubrication are usually more closely related to gasoline engines than to stationary kerosene engines; for this reason agricultural tractors are here only briefly mentioned. The following sections therefore refer to:

Automobile engines.
Motorcycle engines.
Aeroengines for airplanes, airships, etc.
Agricultural tractors.

AUTOMOBILE ENGINES

Classification.
Number of cylinders: 1 to 8, usually 4 to 6.
Horsepower per cylinder: 2.5 to 25 hp.
Speed: 1,000 to 3,000 r.p.m.
Cooling: Nearly always water cooling.
Piston rings: 2, 3, or 4
Piston diameters: 60 to 150 mm.
Piston strokes: 60 to 180 mm.
Piston-skirt clearances: cast iron: 0.003 to 0.008 in.; aluminium alloy: 0.008 to 0.012 in. (chiefly for airplane engines).

Cylinders.—Practically all automobile engines are of the four-stroke cycle type with four or six vertical cylinders. A few low-power automobile engines have one or two cylinders, usually vertical, rarely horizontal. Six- and eight-cylinder "V" type engines are coming into use in high-power cars.

Cooling.—Automobile engines are practically always water cooled. Air-cooled engines are less frequent than formerly and are not likely to increase in numbers, as water-cooled engines give greater security of operation over long periods of service.

Piston Rings.—The number of piston rings is usually three or four, more often the former. In a very few engines the number has been reduced to two, and there is probably no question about the soundness of reducing the number of piston rings to two or three if they are well designed and pegged. The piston friction consumes more than half the total amount of friction so that by having fewer piston rings the piston friction is appreciably reduced.

The question of oil-scraper rings has been the subject of much discussion. The following remarks on scraper rings are gleaned from Philip H. Smith's book on "Excessive Oil Consumption in Diesel Engines," Constable & Co. Ltd., London (1935), to which the author refers for further information.

If pistons and cylinders are properly designed and manufactured, there seems to be no need for scraper rings. If, however, oil-control rings or scraper rings are fitted, they should always be fitted below the gudgeon pin. Figure 179 shows a beveled scraper ring which is not satisfactory, as, when the ring wears, the pressure against the wall is reduced, and the oil from the interior of the piston surges into the holes as the piston passes top center.

A better ring is shown in Fig. 180, where the oil cannot so easily be forced back through the drainage holes.

A still better ring is shown in Fig. 181, a slotted one with horizontal drainage holes at the back. It has a groove cut around the middle, which may be over half the working face. Excess oil is led through a series of saw cuts to the back of the ring and thence through the drainage holes to the interior of the piston.

Even better is the Simplex ring (Fig. 182) considered. Fine saw cuts are made right through the piston ring in two parallel planes and staggered, the rings thus being axially compressible as a spring. It is fitted into the groove with interference fit; *i.e.*,

the axial dimensions of the ring are made slightly larger than those of the groove. If the flats of ring and faces of groove are true and the valve tight, oil cannot creep round and short-circuit the groove, as in other types.

The Simplex ring may be made without drainage holes at the back of the ring, but if it has to cope with a large excess of oil, drainage holes are desirable.

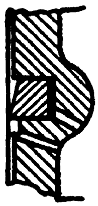


Fig. 179.

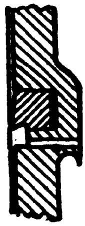


Fig. 180.

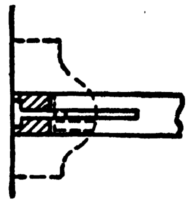


Fig. 181.

This ring may be made with so little axial pressure, arising from interference fit, that inertia force, as the crank passes top center, is sufficient to cause the ring to close slightly, squeezing oil out of the saw cuts and delivering it to the cylinder walls, thus assisting in decreasing wear.

Smith actually found this to be the case on his car, the wear with the Simplex ring after 15,000 miles being only 0.000163 in. per 1,000 miles; taken over 33,000 miles it was only 0.000183 in.

Fig. 182.

When the rings are worn and loose in their grooves, they act virtually like oil pumps as they shift up and down in their grooves, alternately drawing in oil from below and delivering oil upward.

It is therefore very important that the grooves as well as the rings be perfectly made with suitably *small* clearances, say 0.001 in., or so, and they should be only slightly harder than the piston metal, say a difference of 20 to 30 Brinell.

In light-metal pistons (aluminum alloys), the movement of the rings may tend to wear the bottom of the grooves. To counteract this action, some makers cast into the piston a ring holder made from a metal of suitable hardness, *e.g.*, a special cast iron containing 15 per cent nickel and with a coefficient of expansion

approaching that of the aluminum alloy, so that it does not work loose during use.

The rate of wear is always much greater in the cylinder than on the piston, and the maximum cylinder wear is near the topmost point reached by the rings, as this portion of the cylinder not only is highest in temperature but also is exposed for the longest time to the effect of the burning cylinder charge.

Fine clearance between piston skirt and bore is very desirable to give good piston-ring action. Tilting or side movement of the piston causes rubbing of the rings in their grooves, which eventually means loose rings and heavy oil consumption.

As the piston moves up and down in a warm cylinder, the rings alternately expand and contract, which also causes groove wear and increased oil consumption.

Cylinder liners are sometimes employed as a means of prolonging the life of the engine, partly because the liner material then can be specially selected for low wear and partly because the liners may be renewed.

Piston rings should preferably be pegged, as unpegged rings may rotate in use and often get into line, which allows the oil to pass freely to the top of the piston. When piston rings are allowed to rotate and remain round while the cylinders become slightly oval, it is difficult for the rings to maintain a complete seal, as the oil film is too thick at certain points and therefore unable at those points to keep compression or explosion tight. This applies particularly to engines that have been in use for some time and have become worn. A good method of pegging is shown in the illustration (Fig. 183). This method prevents unscrewing of the peg and does not weaken the ring. In the early days, piston rings were nearly always pegged as the desirability of pegging was realized, but unfortunately many pegs came undone and caused great damage to pistons and cylinders. The peg illustrated has, however, given complete satisfaction.

Pistons.—The piston is receiving heat all over the top at a very high rate. This heat must find its way through the piston barrel into the cylinder walls until it finally reaches the cooling water or is radiated into the atmosphere. The heat travels from the center of the piston outward. The piston head should therefore be thicker at its circumference. When the heat gets to the edge of the piston it must flow down the piston barrel, and the

thickness of the barrel below the top piston ring should decrease regularly toward the open end of the skirt.

The piston expands irregularly under heat, owing principally to the gudgeon-pin bosses. Even if the piston and cylinder have been turned and ground quite true, they cease to be round when they become warm. These deformations are not very considerable in the case of cast-iron cylinders and pistons, but with aluminum-alloy pistons this point is particularly important, as the coefficient of expansion of aluminum is twice as great as for cast iron. Aluminum pistons conduct the heat away much more rapidly than cast-iron pistons, the heat conductivity of aluminum being about fifteen times greater. Aluminum pistons therefore

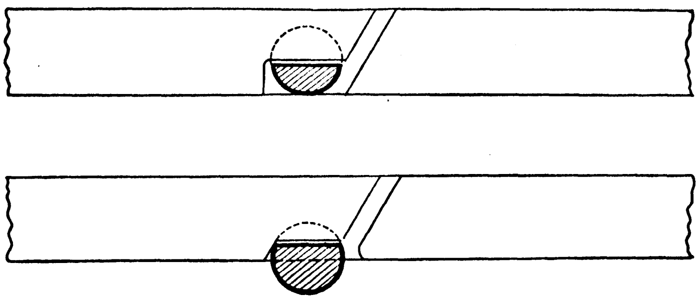


FIG. 183.—Pegged piston rings.

keep much cooler, and higher compressions can be employed without "pinking" (which means detonations caused by excessive compression, due to carbon's reducing the clearance space).

Carbon deposits do not readily collect on aluminum pistons, and preignition is therefore less likely to occur. Aluminum-alloy pistons will increase acceleration, horsepower, flexibility, maximum speed, and mileage per gallon of gasoline and at the same time decrease vibration and carbon deposit, both in the combustion chamber and in the crankcase; they seem therefore to be rapidly gaining favor for automobile engines.

METHODS OF LUBRICATION

The parts requiring lubrication are the main shaft bearings, the crankpin bearings, wrist-pin bearings, camshaft bearings, timing gears, cams, cam-lifter guides, and cylinder walls. Lubricating systems may be classified under five headings:

1. **Full Force Feed.**—Oil is fed under pressure to the main bearings, a portion continuing its way to the crankpins through

drilled holes in the crankshaft, reaching finally the wrist pins through either the hollow connecting rods or the oil pipes attached thereto.

The oil splashed away from the crankpins and wrist pins lubricates the cylinder walls and finally returns to the oil reservoir, being circulated afresh by the oil pump.

2. **Force Feed.**—This system is the same as the full force-feed system with this exception, that the wrist pins are not supplied with oil under pressure but are lubricated entirely by oil spray.

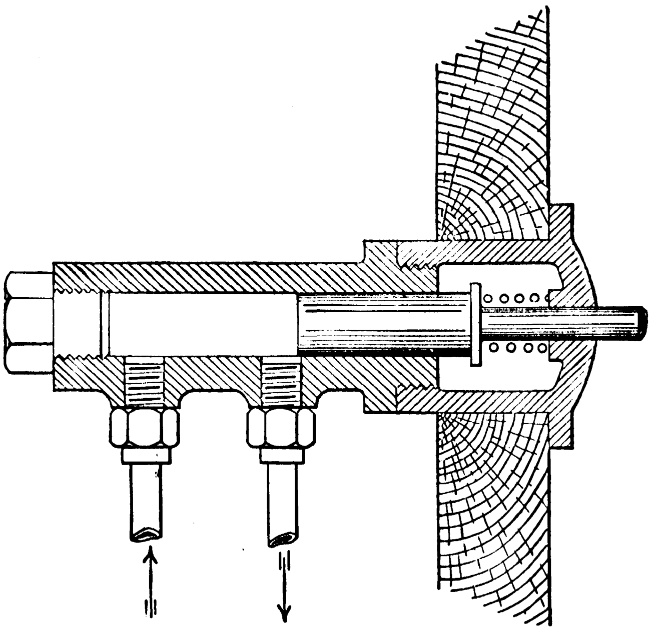


FIG. 184.—Oil pressure indicator.

3. **Force Feed and Splash.**—Oil is forced to the main bearings and crankpins as with the force-feed system, but, in addition, the connecting rods dip into the oil collected in the bottom of the crankcase or in troughs below the crankpins, a constant level being preferably maintained in the crankcase or in the troughs; the oil overflows to the oil reservoir below, whence it is circulated afresh. By this system the oil thrown from the connecting rods is, therefore, not only that leaving the crankpins but also that splashed from the dippers to all parts of the engine.

4. **Semiforce Feed and Splash.**—Oil is supplied at low pressure to a sight-feed arrangement on the dashboard, flowing

from this point by gravity to the main bearings; or it may go direct to the main bearings, while a pressure indicator (see Fig. 184) on the dash shows that the oil is being circulated. The oil leaving the main bearings collects in the bottom of the crankcase or in troughs below the crankpins; the connecting rods dip into it and splash it to all parts. It overflows from the troughs or crankcase into the oil reservoir below, whence it is circulated afresh.

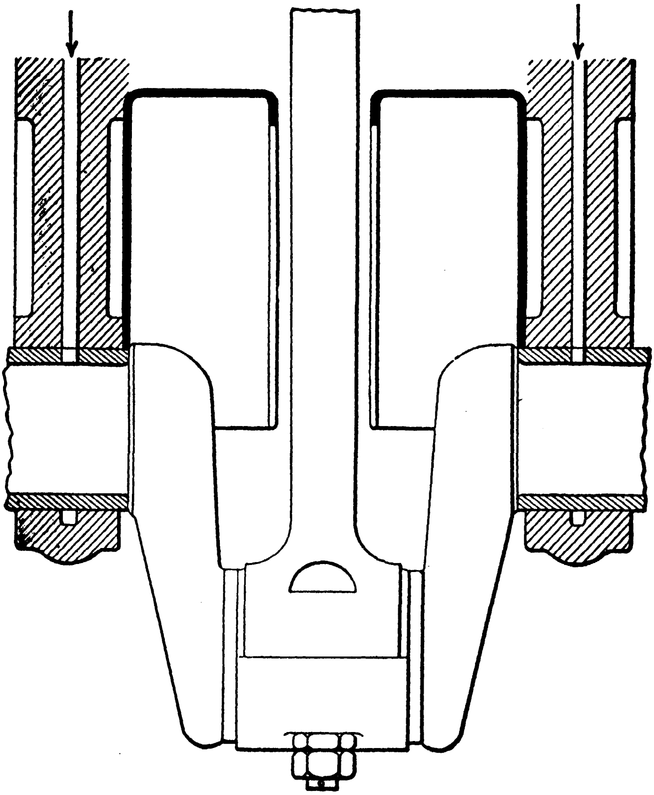


FIG. 185.—Splash guard.

5. **Splash System.**—Oil is supplied to the crankcase; the connecting rods dip into it and splash it to all parts.

Pressure-oiling Systems.—Supplying oil by the full force-feed system to the wrist pins has now been practically abandoned, except for racing cars, as the difficulty in ordinary automobile engines is not that of getting oil to the wrist pins but of preventing too much oil from splashing on to the cylinder walls. With a high oil pressure the large amount of oil leaving the wrist pins tends to overlubricate the cylinders. In fact, with most pressure-

oiling systems, splash guards fitted above the main bearings, as illustrated (Fig. 185), will often prove advantageous, reducing the oil consumption to 1,000 miles per gallon or better, whereas the average oil consumption of motor-car engines is nearer 500 miles per gallon.

The splash guard must be fitted as low as possible over the crankpin path, as otherwise the disturbance in the crank chamber, created by the piston's expelling and drawing in the air through the slits, causes excessive oil spray and increases the oil consumption instead of reducing it.

An oil-relief valve should always be fitted in connection with pressure-oiling systems. This should be so arranged as to measure the pressure at a point near the bearings, and the oil pipes and drillings should be large so that there will always be a good pressure in the crankshaft and no danger of the oil channels' choking up.

A pressure gauge should be arranged to indicate that the oil is circulating under pressure; it is desirable but not necessary to give the actual oil pressure.

Racing-car engines are frequently supplied with oil direct to the piston in addition to the oil spray from the crankcase. Experience proves the necessity of this, the spray from the crank chamber under high-speed conditions not being adequate for the cylinder lubrication.

One weak point in a pressure system is that if the brasses are worn or a slack fit, the oil escapes freely, to the detriment of the other bearings. On occasions, oil pumps have been found to wear, and being worn they have not been able to pump sufficient oil to keep up the oil pressure, with the result that lubrication has failed. For these reasons some builders prefer the semiforce-feed and splash system, which saves drilling the crankshaft.

Briefly, the essential problem of lubrication is to supply the maximum quantity of oil to the bearings without throwing too much on to the cylinder walls. Most pressure-oiling systems fulfill the first of these requirements; and if the oil pressure is reasonably low, and if suitable splash guards are fitted, and the piston rings are pegged, the cylinder lubrication will not be excessive.

With the pressure-oiling systems, main bearings and crankpin bearings have worked for long periods without any wear at all, a result that can never be obtained with splash lubrication.

With splash lubrication a slight alteration in the oil level means either overlubrication or underlubrication. The margin of safety is undoubtedly greater with pressure-oiling systems.

Splash-oiling Systems.—The oil spray is produced by dippers fitted to the big ends. These dippers should be only 1/16 in. wide and, say, 1/4 in. deep, and when cutting through the surface of the oil they should dip to a depth of only 1/16 to 1/8 in. If the dippers are wider or dip more into the oil, the excessive oil spray thus formed means unnecessary waste and carbon deposit.

In the early days the dippers were made in the form of a tube with the point bent forward, belief being that the oil would find its way in through the tube and into the crankpin bearings. A moment's consideration will, however, show that the centrifugal force will at all times be sufficiently strong to throw out any oil that might be present in the oil tube. The effect of the dipper is merely to spray and splash oil to all parts of the engine, and the entrance of the oil to the crankpins should be made from above, the oil collecting on the lower end of the connecting rod being guided into the oil hole or holes and thus reaching the crankpin bearings.

With the splash-lubricating system and when going up- or downhill, the rear cylinders get too much oil, and the front cylinders are starved, or vice versa. This is the reason why the separate trough system was designed and numerous other arrangements by which the oil pump or the flywheel distributes the oil to separate chambers below each crankpin, in order to ensure satisfactory distribution of the oil also when the car is not on the level.

The trough system is really a splash system in which the oil level can be maintained at the proper height. This system has met with wide favor. The amount of splash varies considerably with the speed of the engine. Some builders have arranged adjustable troughs, which are raised or lowered simultaneously with the opening or closing of the throttle, this being, however, considered by many an unnecessary refinement.

The semiforce-feed and splash system is reliable and can be designed not to cause overlubrication of the cylinders, but it has the disadvantage that the oil is picked up from an open trough in which dirt can collect.

OIL THINNING AND RECONDITIONING

After charging an automobile engine with fresh oil, it is well known that the latter quickly changes its character. Some unburnt gasoline, water vapor, road dust, oil carbon, etc., reach the crankcase and mix with the oil in addition to fine metallic particles of wear.

The admixture of gasoline thins the oil, but finally a state of equilibrium is reached when the amount of gasoline entering the oil equals the amount that evaporates owing to the prevailing oil temperature.

If, for instance, the amount of gasoline is 5 per cent when equilibrium is reached, the viscosity of the oil is about halved, and the flash point is, of course, very much lower than originally. The oil becomes darker in color, partly owing to oxidation from the air, accelerated by the catalytic action of the metallic dust in the oil. A certain amount of petroleum acid develops, which, however, scarcely does any harm.

Every 1,000 to 2,000 miles, it is good practice to change the oil in the crankcase, as the accumulated mechanical impurities in it are obviously not beneficial. If they are removed by a good filter, several thousand miles can be run before changing oil.

The practice of reconditioning used automobile oil is not gaining favor because it really means that the oil has to be freed from gasoline, refined, and filtered so that the value of the used oil is not much more than that of crude oil, and such small refineries cannot be compared with a normal oil refinery with its complete staff and equipment.

All that with advantage can be done by companies owning large fleets of cars or lorries, for instance, is to free the used oil from mechanical impurities by passing it warm through centrifugal purifiers; the other impurities such as gasoline quickly reenter the oil in service, so what is the use of temporarily removing them?

CARBON DEPOSITS

Carbon deposits may develop on the piston heads, between and behind the piston rings, on the valves and sparking plugs, and inside the piston hollows. Carbon deposit on the piston heads may cause preignition and pinking. Deposit behind the rings

may make them inflexible in their grooves, preventing them from functioning properly; the result is "blow past" the piston, excessive friction and wear, and frequently piston seizure. Excessive deposit on the valve seats prevents them from seating properly, causing loss of power.

Carbonized oil inside the piston hollow bakes into a crust which in time cracks and falls into the crank chamber, contaminating the oil, often with disastrous results. Carbon deposits may be due to several causes, such as incomplete combustion, road dust, overlubrication, too thin piston heads, etc.

Incomplete combustion is frequently caused by a badly adjusted carbureter's delivering an incorrect mixture of the vaporized fuel and air. Faulty timing of valves, possibly brought about by wear and unsuitable fuel, will also bring about incomplete combustion, likewise a choked muffler or silencer; another cause is defective or incorrectly timed ignition.

Road Dirt or Dust.—Road dirt or dust is drawn into the cylinders with the intake air and forms a base to which any excess oil will readily adhere. The soot resulting from imperfect combustion will likewise form a base for the building up of carbon deposit. Eventually, the deposit if not removed will increase to such an extent that it becomes incandescent, causing pre-ignition, and resulting in heavy knocking of the engine.

Overlubrication.—The excess oil always chars and causes a certain amount of carbon deposit. Excess oil may be caused by ill-fitting piston rings or worn cylinders, by too high oil pressure, or by too high oil level (splash-oiling system).

The *oil pressure* in pressure-oiling systems is nearly always too high. In order to supply a reasonable flow to the last point in the system, only 4 or 5 lb. oil pressure is usually required. Any excess pressure simply means that too much oil spray is formed inside the engine from the oil leaving the bearings, and this excessive oil spray finds its way out of the engine through the air vent or elsewhere and causes a very excessive consumption of oil. Another portion of the excess oil spray leaks past the pistons to the piston tops and helps to increase the formation of carbon deposit.

Overlubrication of the piston is very general in connection with the splash system of lubrication owing to the oil level's

varying and usually being too high or to the dippers' dipping too deeply into the oil.

Whereas a black exhaust indicates incomplete combustion, a blue one indicates burning of excess oil inside the combustion chamber. When the engine is working with the throttle almost closed, as in coasting, or when the car is standing with the engine running (doctors' cars), the vacuum formed in the cylinder, particularly in high-compression engines, sucks the oil past the pistons into the combustion chamber. When the car comes under normal load again the accumulated oil is burned, giving a blue smoke in the exhaust, and the result is the formation of carbon deposits.

When the piston rings are worn they should be renewed; and whether the cylinders are worn or not, pegging of the piston rings will always help to overcome carbon trouble by maintaining a better piston seal.

Carbon deposits may be formed inside the hollow of the piston caused by too thin a piston head. Heat entering the center of the piston cannot get away quickly enough when the piston head is thin. The result is that the piston gets overheated and the oil splashed up into the piston from the crank chamber burns and chars. For ordinary automobile engines the thickness of the piston head (cast iron) must not be less than ¼ in.

TRANSMISSION

The transmission consists of clutch, gear box, and rear axle.

Clutch.—The clutch is located between the engine and the gear box, and there are two main types of clutches, *viz.:*

1. Metal-to-metal clutches.
2. Leather or fiber-faced clutches.

The latter require no lubrication of the contact surfaces, but the leather requires dressing with neat's-foot or castor oil at intervals, say every 500 miles, in order to preserve it. Metal-to-metal clutches must be lubricated in order to prevent wear of the metal surfaces and ensure easy operation.

Experiments have been carried out with multiple-disk clutches showing that without lubrication the friction losses and the rise in temperature are quite small, but oil is required to prevent rusting and abrasion of the plates and to make the plates engage

without gripping fiercely. A very thin lubricating oil is required with a view to minimizing the friction losses. At the same time the oil must have sufficient oiliness to prevent abrasion of the metal surfaces and sufficient viscosity to act as a cushion when the disks or plates are forced into contact.

If the oil is too heavy in viscosity, it becomes difficult to disengage the plates, and it may not be possible to uncouple the engine quickly enough. If an oil too light in viscosity is used, excessive wear takes place, and the plates grip too fiercely.

With insufficient oil in the clutch overheating and wear take place, but the oil level must be kept below the clutch spring.

With a view to preventing abrasion of the plates an admixture of fixed oil is desirable. A very suitable mixture is one containing, say, 10 to 20 per cent of sperm oil with a viscosity not exceeding 120 sec. Saybolt at 104°F. A mixture of the engine oil with, say, 50 per cent of kerosene is often used with good results.

Gear Box.—The gears are best lubricated by means of oil which should be filled into the gear box to the proper level. If the level is too high, the oil runs out of the gear-shaft bearings. If it is too low, the gears do not dip sufficiently to splash the oil to all parts requiring lubrication.

The gears are a source of great loss of power. Experiments carried out by the National Physical Laboratory, Teddington, England, showed that when the gear box of a 32 hp.-Leyland gear box was filled with thin oil to a depth of ¼, ½, ¾, 1, the efficiencies of the power transmission were 97.5, 94, 90, and 74 per cent; thus the efficiency is appreciably reduced when the box is more than a quarter full. These experiments were made on the top gear, but corresponding results were obtained on the second and third gears. Other oils were tried, showing that the losses increased in direct ratio to the viscosity of the gear oil.

Makers are beginning to realize the importance of keeping a proper oil level; and instead of the oil's being filled in from the top, when it is practically impossible to judge whether the correct level has been obtained, the arrangement illustrated in Fig. 186, with a filling plug from the side, is being adopted by a number of builders.

A refinement recently introduced is to have a trough below each gear wheel, into which each wheel dips. The gear oil is circulated

by a pump to keep the troughs filled with oil. It has also been proposed to squirt the oil into the mesh of the teeth. Both with this system and with the one just mentioned thick gear oil cannot be used, as it cannot be pumped. The gear box must therefore be so constructed that a low-viscosity gear oil can be employed without excessive loss of oil.

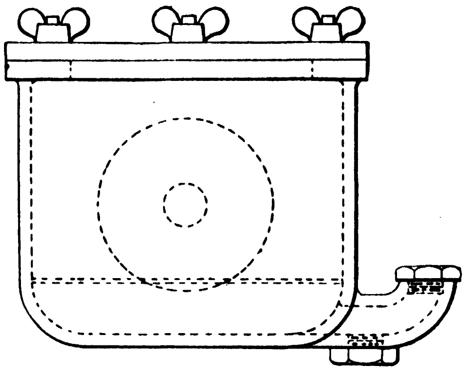


FIG. 186.—Oil-filling arrangement for gear case.

It is obviously desirable to use as low a viscosity oil as possible, and the only reason why the engine oil is not used in the gear box is because the gear box is not sufficiently tight to permit the use of such an oil, so that in order to prevent excessive leakage a heavy-viscosity oil is used or even a semisolid lubricant—a so-called "transmission grease."

Transmission grease may be more economical than oil but has the disadvantage of causing greater loss in power, and it does not distribute itself effectively to all bearings, so that trouble is often experienced, particularly when there are ball bearings in more or less inaccessible positions.

Greases that are too stiff or made from unsuitable materials harden in use and cause excessive heating. The oil melts out; the revolving gears cut tracks in the grease and leave the gears without any lubrication whatsoever.

When the gears are inclined to engage noisily, a heavier viscosity oil must be used or even a transmission grease. The transmission grease should be of soft consistency, known in the trade as No. 2 consistency or even softer, and should preferably be strained during manufacture. The lime-cup grease variety is less inclined to cake and harden than the solidified oils—so-called "soda greases."

Rear Axle.—The remarks made regarding the oil level in gear boxes also apply to rear-axle casings, and it is desirable to fit a filling plug similar to the one shown in Fig. 186.

The oil level must not rise so high as the axle housing, because, notwithstanding the packings provided, the oil will then find its

way along the housing, pass through the outer bearings to the brake drums, and cause the brakes to slip. Oily brake drums are sure evidence of excess oil in the rear-axle casing.

When the packings and bearings are worn, a transmission grease or a mixture of grease and heavy gear oil must be used to prevent leakage, but ordinarily a heavy-viscosity gear *oil* should be preferred.

In case of the worm-wheel drive, the pressure between the worm and the worm wheel is very great, and only oils having great oiliness will prevent wear and give satisfactory results. For this reason several builders are recommending castor oil or so-called "high-pressure lubricants," for the worm-wheel casing.

Experiments prove that all heavy-viscosity fixed oils give better results for the worm lubrication than any type of mineral oil, but the heavy-viscosity filtered cylinder oils come very near in lubricating qualities to the fixed oils and, being much lower in price, are almost universally used, preferably compounded with from 5 to 10 per cent of fixed oil.

The grease used for wheel bearings and other parts should also be of a No. 2 consistency, in order to distribute itself all over the ball- or roller-bearing surfaces. Most oil firms today sell a No. 3 consistency, which has been the cause of innumerable failures of bearings, through failing to reach all parts, with the result that rusting and corrosion have set in, and the bearings have been ruined. The grease must comply with the requirements for a ball-bearing grease as outlined on page 192. That used for the water-pump bearings should be a high-melting-point grease of, say, No. 4 consistency.

Chain Drive.—Where a chain drive is employed, the chains, being exposed, quickly become covered with dirt and dust. They should be oiled daily with the engine oil (gear oil does not penetrate to the link bearings), but it is important to clean them frequently, say every 1,000 miles, by soaking them in kerosene and afterward immersing them in a bath of molten graphite and tallow. By this treatment the chain will get thoroughly soaked with lubricant, and wear will be minimized.

Lubrication of Other Parts.—The lubrication of parts of cars other than the engine, transmission, and rear axle is, as a rule,

much neglected, and for this reason all parts should be designed with a view to maintaining good lubrication, even if the parts do not get the very best attention.

Shackle pins, for example, are now made much larger than in earlier days, and instead of being lubricated by grease they are frequently designed with oil lubrication. A neat method is to place in each pin a small ball valve which, when oiling, is pressed from its seating by the spout of the oilcan.

When semifluid lubricants are employed for this purpose, a grease "gun" may be used, the mouthpiece being pressed into small ball-valve attachments and thus enabled to deliver the grease into the bearings with great force.

MOTORCYCLE ENGINES

Classification.—The vast majority of motorcycle engines are vertical, air-cooled, single-cylinder engines, operating on the four-stroke cycle principle. Other types have two cylinders, either placed horizontally—opposed type—or at an angle—V type. Two-stroke cycle engines are coming into use as vertical one-cylinder engines, usually of small power.

Horsepower: 1¼ to 8.

Speed: 2,000 to 5,000 r.p.m.

Piston Rings.—Pistons in four-stroke cycle engines usually have three piston rings. Pistons in two-stroke cycle engines usually have only two piston rings, and they are nearly always pegged.

Piston Diameter, Stroke, and Clearance.—Piston diameters range from 60 to 80 mm. Piston stroke ranges from 60 to 100 mm. Piston clearances range from 0.002 to 0.005 in. usually 0.003 to 0.004 in.

Compression.—50 to 80 lb. per square inch.

Bearings.—Roller bearings with short rollers are frequently used for the connecting rods and main bearings in order to reduce friction and lubrication difficulties.

Lubricating Systems.

1. Hand pump.
2. Semiautomatic drop feed.
3. Mechanically operated pump.
4. Oil-gasoline system.

1. *Hand Pump.*—The principle of "little and often" should never be forgotten where the oil is fed to the engine crankcase by hand pump. It is better to give half a charge every 50 miles than one charge every 100 miles. Where the oil is introduced at great intervals it means overlubrication after giving the charge, possibly followed by underlubrication later on.

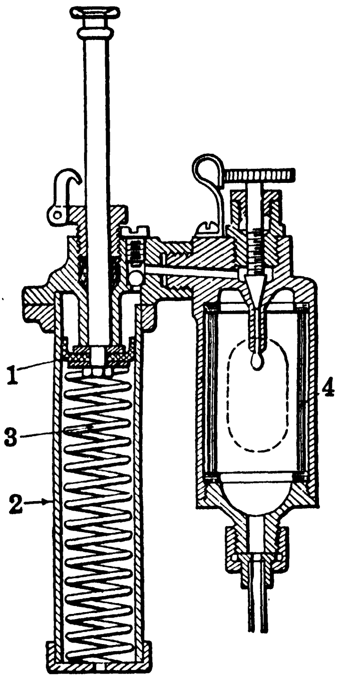


FIG. 187.—Sight-feed lubricator for motorcycle.

Care must be taken when raising the pump plunger to make sure that the pump barrel fills with oil. When the oil is cold and thick it is not uncommon to have considerable engine trouble, simply because the oil never enters the hand-operated pump, and because the rider has no means of ascertaining whether it is being pumped. For this reason even hand pumps should preferably be fitted with some means in the way of sight feeds that indicate to the rider whether or not the oil is being pumped.

2. *Semiautomatic Drop Feed.*—Several sight-feed lubricators have been designed to give a more or less continuous feed of oil, one of the best being illustrated in Fig. 187. The plunger (1) is depressed, and the pump barrel (2) fills with oil from the supply tank. The spring (3) will then endeavor to force the piston upward, discharging the oil through the sight feed (4), from which the oil is delivered to the engine. It is delivered under a pressure of a few pounds per square inch and may therefore be delivered either to the crankcase itself or to the piston, main bearings, etc., as required.

By this lubricator a fairly regular feed of oil can be maintained, but of course the feed will vary with the temperature and the viscosity of the oil and is easily interfered with if dirt gets in between the adjusting needle and its seat. As, however, the rider can always watch the sight feed, any difficulty in this direction is quickly discovered and easily remedied.

3. *Mechanically Operated Pump.*—There is a distinct tendency toward the more general use of this system, which consists of

a plunger pump, preferably with adjustable pump stroke and operated by means of gearing from the engine.

It is very desirable that the speed of the plunger be as low as possible, as otherwise a low oil feed cannot be maintained with certainty, because of the exceedingly short stroke of the plunger.

The mechanically operated pump should preferably be provided with a sight-feed arrangement in order that the driver may know whether the pump parts are in working order and the oil is discharged regularly to the engine.

4. *Oil-gasoline System.*—In this system the oil is mixed with the gasoline in proportions ranging from 1 part of oil to 4 to 10 parts of gasoline, and the lubrication of the engine is therefore not dependent on the skill of the rider.

There are, however, many disadvantages to this system. If too much oil is used, excessive carbonization takes place; and if an attempt is made to reduce the proportion of oil, it is frequently found that the engine is poorly lubricated, particularly when the latter has been in use for some time and has become slightly worn. The engine runs with a harsh noise indicating that the running parts are not properly lubricated.

Oil has also a tendency to combine with the road dust which is always drawn in with the air through the carbureter, the effect of this being to clog the working parts, particularly the needle.

Points of Delivery.—The simplest method of lubrication is to deliver the oil straight to the crankcase, so that the flywheel dips in and distributes it to all parts by creating an oil fog in the crankcase. This is the method practically always used in connection with hand-pump lubrication. Many manufacturers provide ducts cast in the crankcase which collect the oil spray formed by the flywheel and distribute it to the main bearings, etc.

In modern motorcycles the development is, however, in the direction of feeding the oil first of all to the main bearings and sometimes also to the piston, the oil escaping from the main bearings being caught by a rim on the flywheel and by centrifugal action carried into the big end. Feeding oil direct to the piston appears to be necessary only in high-power engines and for racing purposes. Lubrication of the gudgeon pin is usually well taken care of by the oil fog alone.

In most systems the oil, having done its work, collects in the sump at the bottom of the crankcase, is drawn off at intervals,

and is not used over again. In some systems, however, it is circulated over and over again through the main bearings, the oil feed being very slow and done by means of a mechanically operated pump.

Carbon Deposit.—In case of overlubrication, excessive carbonization takes place on the top and in the hollow of the piston. In order to prevent the formation of carbon deposit inside the piston, some motorcycles are made with a distance plate over the gudgeon pin, which never attains a temperature high enough to carbonize the oil splashed up from the crankcase. This arrangement also keeps the crankcase and the working parts enclosed therein much cooler.

In order to keep the piston rings compression-tight, all two-stroke engines should have their rings pegged, so that they will wear to a fit with the cylinder. If they are not pegged, they are inclined to move in their grooves until the gaps get into line, resulting in bad compression, excessive carbonization of the oil, an overheated crankcase, and heavy wear. The method of pegging the rings should, of course, be such that under no circumstances can the pegs unscrew and damage the cylinder (see page 502). It is the excess oil that causes carbon deposit and to which impurities arising from bad carbonization, bad combustion, or road dust will adhere.

Oil Consumption.—The oil consumption for motorcycle engines ranges from 1,000 to 4,000 miles per gallon of oil, the average being 2,500 miles per gallon.

Oil.—It is very important that the oil should have a sufficiently low setting point, say 20 to 25°F., so as to flow freely during the winter season; poor cold-test oils may not reach the working parts, and the engines are difficult to start when cold.

Motorcycles usually do not get too good attention, being often in the hands of men who have had little or no technical training. As a result, plenty of oil is the cure-all employed for most troubles. Such overfeeding with oil means that a great deal of the excess oil is burnt inside the cylinder, and oil manufacturers should therefore aim at producing an oil with a particularly low tendency to carbonize. That can be accomplished by using pale, nonparaffinic-base oils, compounded with, say, 10 per cent of good-quality fixed oil.

A low content of free fatty acid is desirable from the point of view of bearing lubrication. A high percentage does not seriously affect the cylinder lubrication, although when the engine is put aside for some weeks, the result is usually to be seen in heavy rusting of the piston, rings, and cylinder due to the acid. The real trouble caused by free fatty acid is, however, corrosion and pitting of the balls or rollers in the bearings. For this reason only fixed oils having a low percentage of free fatty acid, say below 5 per cent, should be used.

Semidrying oils like rape oil, cottonseed oil, and whale oil should not be employed on account of their gumming tendency, as the choking of oil grooves, etc., may easily cause much trouble.

The following tests are characteristic of good motorcycle oils which will suit practically all motorcycles:

Specific gravity	0.900 to 0.930
Setting point	20 to 25°F. for winter use 30 to 40°F. for summer use
Open flash point	400 to 420°F.
Fire point	440 to 465°F.
Viscosity (see page 57)	No. 10 (76 centipoises at 50°C.)
Compound	10 per cent good-quality fixed oil

AEROENGINES FOR AIRPLANES, AIRSHIPS, ETC.

The three main types of aeroengines are:

Rotary engines, with revolving cylinders, air cooled.

Radial engines, with cylinders radially arranged, either air or water cooled.

V-type engines, with inclined double row of cylinders, mostly water cooled.

Rotary Engines.—The rotary-type aeroengine, *e.g.*, the Gnome, presented from the beginning a great many lubricating problems. In the early types the inlet valve for the gasoline-air mixture was in the center of the piston, and this valve became easily choked with deposit. In a later type, the Monosoupape (single valve), one valve placed in the top of the cylinder serves as both exhaust and inlet valve, thus doing away with the inlet-valve troubles of the earlier type.

Only one piston ring is used, made from sheet brass or phosphor bronze and of L shape, as illustrated in Fig. 188. On the

compression and the explosion stroke the ring is expanded by the pressure in the cylinder and at the same time is forced down on its seating in the piston-ring groove, which also holds a light piston ring of the ordinary type in order to keep the expanding piston ring in position. This ring, being the only one, must be an absolute fit in the steel cylinder, and it has a vertical straight cut at the point where its two ends meet. This cut is the weak part of the ring and is eaten away by even a slight trace of fatty acid in the castor oil used for lubrication. As soon as the

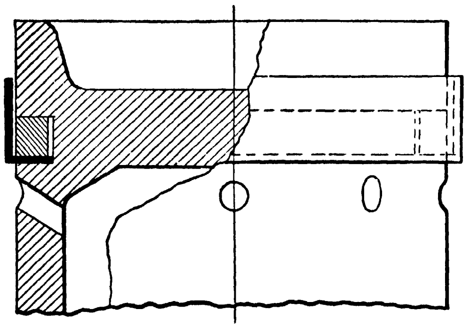


FIG. 188.—"Gnome" piston with single piston ring.

corners of the cut in the brass ring become rounded, the ring is no longer able to prevent the explosion gases from passing the piston; and the cylinder immediately becomes overheated in a straight line following the position of the cut in the ring. The cylinder in question will be found out of shape, being only about $\frac{1}{16}$ in. in thickness, and must be replaced.

The gasoline is introduced through the hollow shaft and immediately evaporates inside the crank chamber. Gasoline has a dissolving effect on mineral lubricating oil but does not affect castor oil, so long as the latter remains cold.

The lubricating oil is fed to the oil pump through a tube from an elevated oil tank. This makes it necessary in cold weather, in case the airplane rises to a considerable height, to use an oil with a good cold test, say not above 0°F. It is good practice to empty the oil tank every night and before a new flight to put the oil into the tank hot. The tank should preferably be placed so that it may benefit to some extent by the heat from the engine during flight.

By means of a mechanically operated plunger pump with piston valves the oil is introduced through the hollow shaft

under a slight pressure, and the main stream divides itself in seven different directions, *i.e.*, for supplying oil to the seven different crankpins, connecting rods, gudgeon pins, and pistons. Obviously, the oil holes all being very tiny, the amount of resistance to the oil will differ, and if there is a slightly greater resistance in one direction than in the other six, this will mean that in order to give sufficient oil in the one direction, it must be fed very copiously. This is one of the reasons for the heavy oil consumption is this type of motor. Another reason for a heavy oil consumption in the Gnome motor is the fact that it is a rotary engine and that the centrifugal force tends to throw the oil outward and to tear it away from the cylinder walls.

This means that in order to keep a sufficiently thick oil film on the cylinder walls, there must be a constant spray of oil to make up for that which is thrown out through the cylinders as a result of the centrifugal force. As the engine is air cooled, the top portion of the cylinders gets very hot; in fact, the metal turns blue. Consequently, all the oil used for lubricating the pistons, etc., is eventually burned in the combustion chambers; and if it leaves deposit, the carbon will soot up the sparking plugs and prevent the valves from seating properly.

For the old type of Gnome motor the oil consumption was about 80 g. per horsepower-hour. With the "Monosoupape" engine the consumption has been reduced to about 25 g. per horsepower-hour. If the oil consumption is reduced below these figures, the margin of safety is so low that there is danger of one or several of the pistons' seizing.

Experience generally with internal-combustion engines proves that whenever the cylinder consumption of mineral lubricating oil exceeds 5 g. per brake horsepower per hour, excessive carbonization, due to burning of the excess oil, takes place. Mineral lubricating oils can therefore not be used for lubricating the Gnome or any other rotary type of airplane engine, but this is not the only reason. Mineral lubricating oils are deficient in oiliness as compared with fixed oils. They do not cling sufficiently to the cylinder walls to provide efficient lubrication; they are thrown out through the the cylinders so quickly that the cylinder walls are left dry; and if the engine runs with such oils for more than a few minutes, the pistons seize, the cylinders become overheated, and the speed of the engine falls below normal. If exceed-

ingly viscous mineral lubricating oils are used, it has been proved possible to maintain the cylinder walls in a greasy condition, but the fluid friction of such oils is so high that the engine loses power, and the speed is reduced. Furthermore, such oils produce a very excessive amount of carbon deposit which is obviously fatal, and, finally, they have a poor setting point; for this reason alone they could not be accepted, as airplanes are exposed to cold weather, and the oil would congeal.

Medicinal castor oil, practically free from fatty acid, is the only oil that has given satisfactory results for rotary-type airplane engines. It can be used in great excess without leaving any carbon deposit inside the cylinders; all the oil passing through the combustion chambers burns away clean. Castor oil is only slightly affected by the gasoline vapors in the crank chamber. It has sufficient viscosity to seal the pistons and sufficient oiliness to keep the cylinder walls well lubricated in spite of the centrifugal force, and it has a viscosity sufficiently low that the speed of the engine can be maintained at normal for long periods. Castor oil has a good cold test and will not congeal in cold weather or at high altitudes.

Radial and V-type Engines.—The great majority of aero-engines are now of the radial type or the V type. Although these engines operate very satisfactorily with castor oil as a lubricant, yet there is not the same need for castor oil as in the case of the rotary-type engine. The oil is kept warm in the engine and circulates continuously under pressure. The question of cold test is therefore not so important; and, as the centrifugal force does not act here as in the case of the rotary-type engines, lubricating oils, largely mineral in character, can nearly always be employed with complete satisfaction. It is advisable to have a certain percentage—about 10 per cent—of good fixed oil, say neat's-foot oil, mixed with the mineral oil in order to minimize the danger of seizure and to reduce friction. Castor oil can also be used in such mixtures but only in the presence of an animal oil. An admixture of 5 per cent of castor oil and 5 per cent of lard oil or neat's-foot oil forms an excellent mixture. If more castor oil is desired, as much as 20 per cent can be mixed with 74 per cent of asphaltic-base mineral oil in the presence of 6 per cent of lard oil. By increasing the percentage of animal oil, even greater proportions of castor oil may be employed.

Aluminum pistons are particularly liable to cut and seize during the first 5 to 6 hr. testing, owing to the initial "growth" of the aluminum. It is particularly during this period that castor oil or oils containing a high percentage of fixed oil show their superiority over straight mineral oils.

When aeroengines with aluminum pistons are running at maximum power the piston clearance is reduced to proper working value, but when the engines are running at lower power the lower temperature of the piston brings about larger piston clearances, which explains why under these conditions aeroengines may have a high oil consumption.

The consumption of lubricating oil is usually reduced when using castor-oil mixtures in place of pure mineral oils. Sometimes excessive oil consumption is caused by the oil pressure's being too great. The following figures taken from trials with an eight-cylinder V-type engine developing 200 hp. at 1,400 r.p.m. clearly show the effect of oil pressure:

Oil Pressure, Pounds per Square Inch	Oil Consumption, Gallons per Hour
70	1.5
50	0.9
30	0.5

Aeroengines when used for war purposes are examined and cleaned thoroughly after each trip, so that any gumminess brought about by the use of pure castor oil is removed. When the engine parts are not frequently cleaned, the gummy products of oxidation soon become very troublesome.

AGRICULTURAL TRACTORS

During recent years, agricultural tractors have come much into prominence, and their design has largely been developed following the design of automobile engines, only experience has proved that they have to be built more strongly to stand up to the more severe conditions. They are prone to overheating and therefore must have good radiators and fans in order to keep the cooling water from becoming too hot. In many engines the cooling water is always boiling hot. For this reason very heavy-viscosity oils are generally employed, so as to retain sufficient lubricating power exposed to the higher temperatures.

Kerosene is the fuel generally adopted instead of gasoline, both the fuel and the intake air being preheated by the jacket water and the exhaust heat, respectively, and in some tractors the air passes a dust extractor to prevent dust from entering the cylinders.

Many different systems of lubrication are employed, ranging from splash to force feed, as well as intermediate systems, and in addition a number of tractors have adopted mechanically operated lubricators which distribute the oil by means of plunger pumps to the various points requiring lubrication. As the oil-feed pipes from such lubricators are generally exposed, low-setting-point oils are demanded.

A general endeavor is being made to enclose the gear and differentials and to lubricate them with oil in preference to grease.

They are many different types of agricultural tractors; and although their design often approaches automobile designs, a great many are adaptations of stationary kerosene-oil engines. The lubrication requirements must therefore be studied for each particular type and make, and the author will not attempt to give any specific recommendations in the same way as was done with gas engines.

LUBRICATING OILS FOR GASOLINE ENGINES

The oil must have such a viscosity and setting point that it can be distributed with certainty to all parts of the engine, even in cold weather. Low-setting-point oils are particularly required where the feed pipes are exposed, as is frequently the case in the "semiforce-feed and splash system" of lubrication. A low setting point is always advantageous in a motor oil, particularly during cold weather, because of the greater ease in starting the engine from cold.

The temperature of the cylinder walls in water-cooled engines will not be higher than 250 to 300°F. This moderate temperature enables the lubricating oil to remain on the cylinder walls and perform its function as a lubricant. The inner surface of the oil is, however, swept by the hot explosion gases, the maximum temperature of which is about 2500°F., and the inner part of the oil film is therefore continuously being burned away. Some oils volatilize without leaving residue; others decompose and deposit free carbon similar to what happens when cracking oils during

distillation. Lubricating oils made from naphthenic- and asphaltic-base crudes belong to the first-mentioned variety and have therefore proved better oils for motor cylinders than paraffin-base oils, which are more inclined to crack and form carbon.

As the piston lubrication is imperfect (boundary lubrication), the oil molecules nearest the metallic surfaces are subject to great heat (see page 86), and polymerization takes place which darkens the oil and develops tarry products which may deposit when the oil cools.

Leading oil firms have therefore in many different ways attacked this problem by adding to the oil so-called stabilizers which have the effect of keeping these products dissolved in the oil at all temperatures.

Pale, low-setting-point, nonparaffinic-base, well-stabilized oils are therefore the best lubricants when considering the *cylinder requirements* only. Air-cooled cylinders obviously require oils of higher viscosity than water-cooled cylinders. As the same oil is used for lubricating cylinders and bearings, the requirements of both must be taken into consideration when selecting a motor oil.

Bearings with small clearances are usually lubricated by a *pressure-oiling system*, and *oil of practically any viscosity can be used* as long as the pump will circulate it.

In order to guard against the oil pressure's dropping too low (worn oil pump, worn bearings, choked oil passages), medium- or heavy-viscosity oils are nearly always used with pressure-oiling systems.

Bearings that are worn and have large clearances *need a heavy-viscosity oil* to prevent knocking.

With the *splash system of lubrication* a *thin or medium-viscosity oil must always be used* because a heavy-viscosity oil cannot be splashed to all parts with certainty.

The use of an oil of the wrong viscosity will cause wear, owing either to the oil's being too light in viscosity or to the fact that the oil is too viscous to be distributed with certainty under the conditions prevailing in the engine. Whereas wear of the crankpin bearings or main bearings is indicated by a dull thumping noise, wear of the wrist pins is indicated by a clear metallic knocking.

Thinning of oil has been generally experienced during recent years, due to the use of unsuitable gasoline substitutes or petro-

leum spirits containing too high a percentage of "heavy-end" products. The less volatile products pass the piston freely and thin the oil in the crank chamber. The only remedy is to use a heavier viscosity oil than the one known to give satisfaction, changing the oil in the crankcase more often, at least every 2,000 miles.

It is a curious fact that the heavy ends at the same time as they cause thinning of the oil tend to keep the pistons clean and free from carbon deposit. They are of a kerosene nature and are present on the piston in liquid form. Their cleansing action is therefore akin to the effect of mixing kerosene with lubricating oil to give cleaner piston lubrication in large gas engines.

Thinning of the oil due to crankcase heat is experienced with racing-car engines or racing motorboat engines and is counteracted by passing the oil through coolers, *i.e.*, nests of tubes cooled by the air rushing past, or by sea water.

The bearing-oil requirements call for oils that retain their viscosity well under heat. In this respect, paraffin-base oils are better than asphaltic-base oils. For this reason many oil firms use mixtures of asphaltic- and paraffin-base oils so as to produce oils with reasonably low setting points and a fairly low tendency to carbonize and that will not thin too much under heat. Other firms use straight paraffin-base oils highly filtered to remove coloring matter, but such oils ordinarily, when not treated with viscosity inhibitors, have high setting points and produce carbon of a hard brittle nature, although a lesser amount than do dark-colored oils.

The admixture of fixed oil, preferably nondrying like lard oil or coconut oil, improves the viscosity curve and reduces the tendency to carbonize. An admixture of from 5 to 10 per cent of good-quality fixed oil is nearly always conducive to good results.

For racing purposes castor oil is frequently used on account of its excellent viscosity and noncarbonizing quality. Other fixed oils are much lower in viscosity, in fact, too low to give good results unless mixed with heavy-viscosity mineral oils, but such mixtures do not equal pure castor oil for racing purposes.

For everyday use in touring cars, etc., no oils should be used containing more than, say, 10 per cent of fixed oils, as in continuous service all fixed oils produce gummy deposits, which may

choke the oil passages and bring about excessive heating of the bearings or even worse results.

As regards the tendency to carbonize, it has been suggested that a good motor oil (or the mineral base of a motor oil) must have only a slight tendency to emulsification with water and that the percentage of the oil distilling over below 300°C. under vacuum is important. As regards emulsification tendency, water rarely enters the oiling system in an automobile engine, and if it does so accidentally (leaky water jacket), the water will never get a chance to separate from it. The oil pump draws from the very bottom of the reservoir and will certainly churn any water effectively together with the oil in circulation and form an emulsion, no matter what oil is used. But the suggestion is based on an element of truth, because if the mineral oil emulsifies badly with water, it contains a portion of unstable hydrocarbons, which on decomposing, *e.g.*, coloring matter, *may* produce carbon. The author feels, however, that too much value should not be attached to the emulsification test when motor oils are being judged.

As regards the distillation test of motor oils under vacuum up to 300°C., the oil film as a whole is not exposed to such conditions. The author thinks that very little oil evaporates in the oil film but that the inner portion of the oil film is cracked, the oil being suddenly decomposed or volatilized. In the distillation test the nature of the oil undergoes quite different changes.

The carbon test suggested by Conradson (see page 66) or another test on those lines is much more likely to reproduce conditions akin to what takes place inside a motor cylinder.

CHAPTER XXX

TOP LUBRICATION

Recent research[1] indicates that considerable wear takes place in an automobile engine owing to corrosion due to condensation on the cold cylinder walls, especially at starting, when the walls are cold, the products of combustion containing various acids and other corroding substances.

The maintenance of a good oil film is therefore important, also from this point of view, and various oil firms have therefore added certain metallic compounds, so-called corrosion inhibitors, to their automobile oil in order to counteract such corrosion. Another means of counteracting corrosion is to employ colloidal graphite mixed with the automobile oil and/or used as a top lubricant. The graphoid surface promotes the formation of an adsorbed oil film and assists in forming a good film, thus helping to protect the surfaces against corrosion.

The use of a suitable top lubricant was shown by the I.A.E. Research Committee to reduce wear at low temperatures to a third of what it was without the top lubricant, and the opinion was expressed that the full advantage of a top lubricant would be felt if it could be applied in rather larger quantities at starting from cold.

Top lubricants are generally used dissolved in the gasoline; they are therefore able to lubricate the inlet-valve spindles, which ordinarily get no lubrication and may in time develop sluggish action.

From a mechanical point of view, progress has been made by employing "thermostats" in the water-cooling system, the aim being to allow the cooling water to rise quickly in temperature, thereby reducing the time that the engine ordinarily would operate cold.

[1] Institute of Automobile Engineers Research Committee's report on cylinder wear, *I.A.E. Journal*, August-September, 1934.

Running In Engines.—All automobile engines have to be "run in" before they are in a fit condition to leave the manufacturer's works. This running in takes considerable time, and during the operation a certain amount of initial wear takes place of all the frictional surfaces, pistons, rings, cylinders, shafts, bearings, etc.

Experience proves that the time needed for running in and the initial wear are appreciably reduced by mixing colloidal graphite into the oil and the gasoline in suitable quantities. The microscopically small scales of graphite become attached by adsorption of the bearing surfaces and fill up the "valleys" of the irregularities due to machining, so that only the tops of the "mountains" need to be worn away or flattened out during the running-in process, instead of the entire "mountain range" having to be worn away, which obviously means greater initial wear and greater time for running in.

More and more automobile-engine manufacturers seem to wake up to the advantage of using colloidal graphite for this purpose.

Tests carried out by the research department of the I.A.E., approximating road conditions with frequent stopping and starting, were made to compare the rate of piston-ring wear when running in an engine on a lubricant with and without addition of oildag colloidal graphite. The tests showed that with colloidal graphite the piston-ring wear was halved.

INFLUENCE OF ENGINE CONSTRUCTION ON THE CHOICE OF MOTOR OIL

In selecting a motor oil it is necessary to scrutinize closely the details of construction.

High-viscosity oil is called for with large-diameter pistons; long piston strokes (tendency to piston "rocking"); large piston clearance (aluminum pistons in particular); few or ill-fitting piston rings; worn pistons and cylinders; high compression; worn bearings; air cooling or poor water cooling, *e.g.*, agricultural tractors; hot climatic conditions; racing-car engines; most pressure-oiling systems; etc.

Low-viscosity oil is called for with small-diameter pistons, short piston strokes, high piston speed, small piston clearances, normal number of well-fitting or pegged piston rings, low compression,

normal bearing clearances, efficient water cooling, cold climatic conditions, splash-oiling systems, etc.

"Noncarbonizing" oils, i.e., pale-colored, nonparaffinic-base oils with or without admixture of fixed oil, are called for where the oil consumption is excessive. When the oil consumption is maintained at 1,000 miles per gallon or less, one need not fear much trouble from carbonization of the oil.

Admixture of fixed oil appears to be *necessary* or at any rate desirable with aluminum pistons operating in steel cylinders, as aluminum does not work well together with steel and easily "drags" and seizes. Mineral oil does not give the same margin of safety when used straight, *i.e.,* without admixture of fixed oil.

When the *oil consumption is very excessive,* as with the rotary-type airplane engines, only *pure medicinal castor* can be used.

MOTOR OILS

Most oil firms market several grades of motor oil under proprietary names, and each can or drum is also marked with the consistency of the oil, such as light body or medium body.

Opinions differ among oil firms as to what constitutes a light oil, medium oil, and so on, but the following viscosities, setting points, and colors may be considered as representing the best practice for temperate climates. In hot climates low setting points are not needed. The table below gives some characteristics of typical motor oils.

	Extra light	Light	Medium	Heavy	Extra heavy
Viscosity number*	6	7	9	10	12
Setting point, degrees Fahrenheit	0	10	35	40	40
Color, Lovibond (¼-in. cell)	20	30	100	200	300

* See table, p. 57.

Lubrication Chart for Gasoline Engines

Extra Light and Light.—For cars, chiefly of American make, employing the splash system of lubrication, also for many European cars with small-power, high-speed engines. The extra-light grade is usually too light for European cars.

Medium.—This is the correct grade for the vast majority of cars, also for a fair number of motor trucks.

Heavy.—Used largely in Europe for motor trucks and for Continental cars, French and Italian make in particular, employing force-feed lubrication.

Mixed with 6 to 10 per cent of good-quality fixed oil, this oil will suit most water-cooled airplane engines of the V or radial type; it will also prove an excellent oil for most motorcycles.

Extra Heavy.—This grade compounded with up to 10 per cent of good-quality fixed oil is recommended for V- and radial-type air-cooled airplane engines.

Medicinal (Pharmaceutical) Castor.—For rotary airplane engines exclusively.

Clutch Oil.—For multiple-plate metal clutches. This oil should have a viscosity not exceeding No. 3 (see page 57) and should preferably contain 10 per cent of nondrying fixed oil. When clutch oil is not available a mixture of engine oil with at least 50 per cent kerosene may be used.

Gear Oil.—For gearbox and rear-axle casing. A dark or filtered cylinder stock having a rather high setting point usually gives good results. A high setting point makes the oil thick at ordinary temperature, so that none leaks out from the gearbox; but as soon as the car starts running, the oil thins, so that the friction losses in the gearbox are kept low. Some makers give the gear oil a high setting point by mixing with it a percentage of petroleum jelly or paraffin wax. For worm-gear back-axle drives the gear oil should preferably contain 5 to 10 per cent of nongumming fixed oil.

Automobile Charts.—All leading oil companies now issue automobile-lubrication charts giving recommendations for grades of lubricants to be used for the various makes of cars and trucks—for summer and winter use, respectively.

CHAPTER XXXI

KEROSENE-OIL ENGINES AND SEMI-DIESEL ENGINES

As the hot bulb or vaporizer is a characteristic feature of practically all of these engines, they are frequently called hot-bulb engines.

Horizontal oil engines are used for driving shafting and machinery in machine shops, woodworking shops, and dairies, also for driving refrigerating plants, electric generators, pumping machinery, and agricultural tractors and for a variety of purposes in out-of-the-way districts.

Vertical oil engines are used chiefly for marine service, for fishing boats and pleasure boats; they are used also for driving agricultural tractors and for many purposes in out-of-the-way districts, in the same way as horizontal oil engines.

Classification.—Oil engines may be classified as shown below.

Type of oil engine	Number of cylinders	Horse-power per cylinder	R.p.m.
Horizontal, pistons not water cooled	1 to 4	1 to 90	600 to 180
Pistons water cooled	1 to 4	90 to 200	180 to 120
Vertical	1 to 8	1 to 125	900 to 160

Starting.—When starting, the hot bulb is heated to a dull-red color by means of a gasoline or kerosene blowlamp. Engines employing electric ignition are started on gasoline till they are warmed up.

Small oil engines are started by hand; *large oil engines*, by compressed air. The air used for starting is compressed by a small belt-driven compressor operated by the oil engine, and the air is stored in reservoirs.

After starting, the engines operate automatically, and the blowlamp is removed, the hot bulb being thereafter kept hot by heat from the explosions.

Injecting the Fuel.—The fuel is injected under great pressure through a specially constructed spray nozzle in order to produce a very fine fuel spray and achieve complete combustion. Several makers use compressed air of 250 to 450 lb. pressure for injecting the fuel, which greatly assists in producing a finely atomized fuel spray and in getting complete combustion.

In some small engines the fuel is fed by gravity from a tank into the air-inlet valve so arranged that every time the air valve opens, fuel is admitted, atomized by the in-rushing air, and carried into the engine. Obviously, only light oils like kerosene can be used in this manner.

In some semi-Diesel engines the piston head is apt to become very hot and can be kept sufficiently cool only by employing water injection. The hot piston head heats the air in the crank chamber and reduces the capacity of the engine; it also means a warm gudgeon pin. For these reasons it is good practice to make the piston in two parts, a partition plate preventing the crank-chamber air from coming into contact with the piston head.

In vertical oil engines employing force-feed circulation, the piston should be at least $\frac{1}{4}$ in. thick in the center to avoid overheating and carbonization of the oil in the piston hollows.

PRINCIPLE OF OPERATION

Oil engines operate on the four-stroke or the two-stroke cycle principle but by two different methods, the fuel being introduced either during the suction stroke or at the instant of maximum compression (semi-Diesel principle).

Four-stroke Cycle Principle of Operation. *Method* 1 (Fig. 189).—Used practically exclusively in *low-compression* oil engines (40 to 70 lb. compression) employing light fuels, chiefly kerosene.

Stroke 1 (Suction).—Air is drawn in through air-inlet valve, and at the same time (*a*) fuel is admitted into the air (by gravity or carbureter) and atomized, or (*b*) by means of the fuel pump it is injected into the hot bulb and there vaporized. In either case the piston moves outward, the cylinder being filled with a more or less complete mixture of air and fuel vapor, constituting the fuel charge. Exhaust valve is closed.

Stroke 2 (Compression).—The piston moves inward, compressing the fuel charge into the hot bulb to a pressure of 40 to 70 lb. Inlet valve and exhaust valve are closed.

Stroke 3 (Power).—Firing of the compressed-fuel charge by electric ignition or spontaneously by the high temperature existing in the hot bulb;

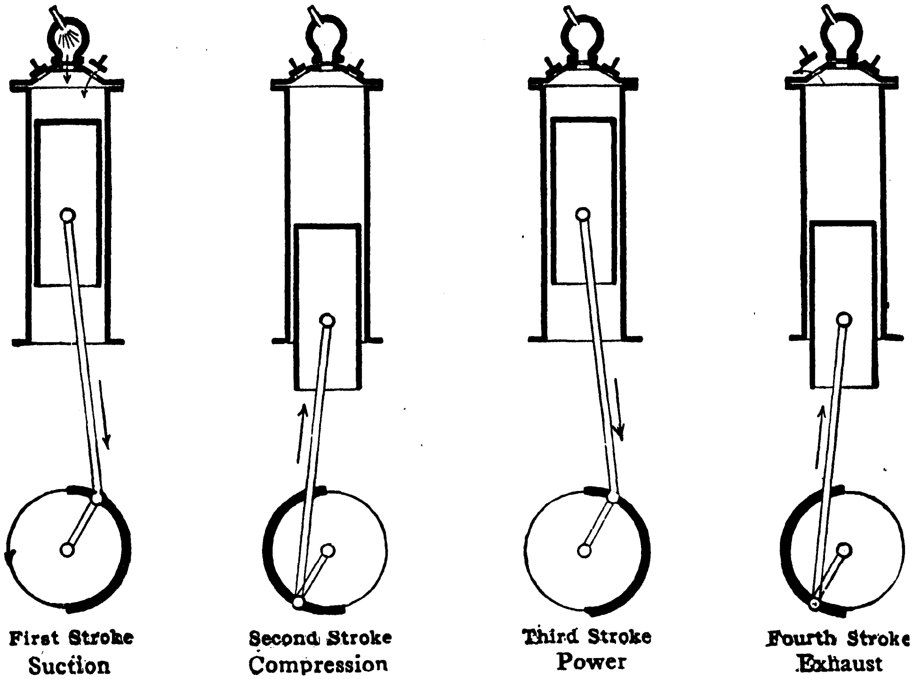


FIG. 189.—Four-stroke cycle principle of operation, kerosene-oil engines.

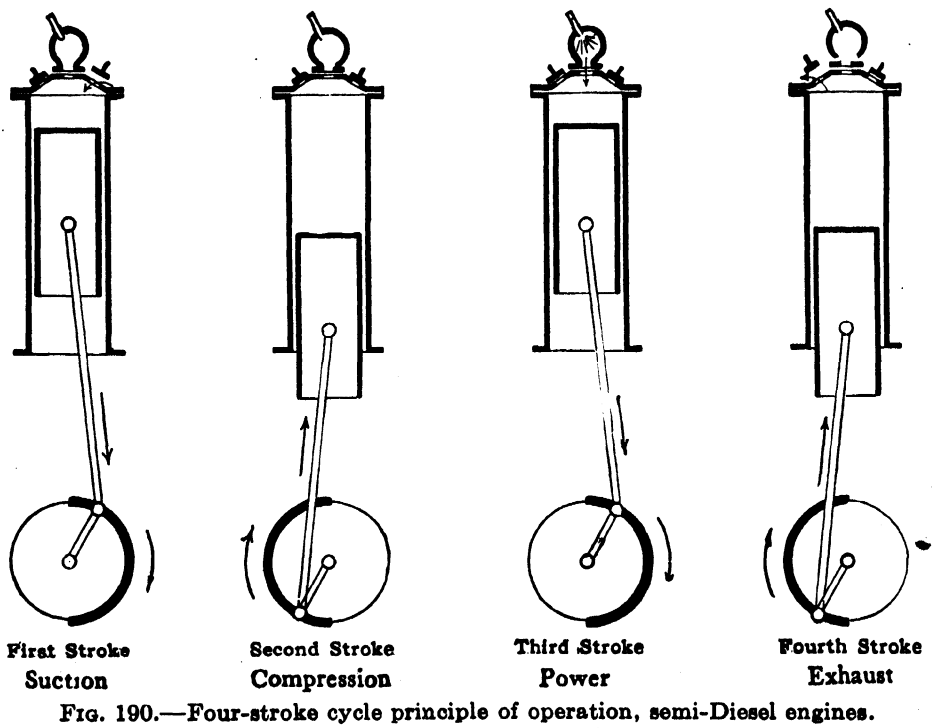


FIG. 190.—Four-stroke cycle principle of operation, semi-Diesel engines.

explosion; and expansion, the piston being forced outward during its power stroke. Inlet valve and exhaust valve are closed.

Stroke 4 (Exhaust).—Piston moving inward, driving out the burnt gases, through exhaust valve. Inlet valve is closed.

A few makers fit an extra valve called a "timing valve" in the "neck" between the hot bulb and the cylinder. It is operated from the camshaft and opens communication between the hot bulb and the working cylinder at the moment when it is desired

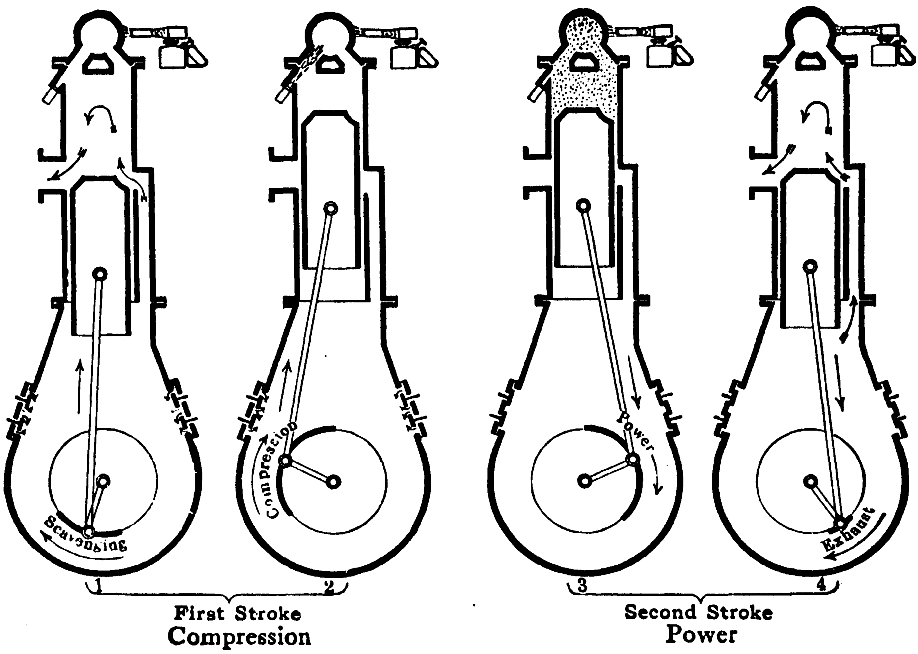


FIG. 191.—Two-stroke cycle principle of operation, semi-Diesel engines.

that the explosion shall take place. A fairly high compression can, therefore, be employed without the danger of premature explosions.

Method 2 (Fig. 190).—Used in four-stroke cycle semi-Diesel engines employing besides kerosene also heavier fuels, such as gas oil and black fuel oil.

Stroke 1 (Suction).—The piston moves outward, sucking in air through the air-inlet valve. Exhaust valve is closed.

Stroke 2 (Compression).—The piston moves inward, compressing the air into the hot bulb to a pressure of 150 to 300 lb. Inlet valve and exhaust valve are closed.

Stroke 3 (Power).—Fuel oil is sprayed into the hot bulb (either solidly or mixed with compressed air); the fuel burns, and the high pressure developed

forces the piston outward during its power stroke. Inlet valve and exhaust valve are closed.

Stroke 4 (Exhaust).—The piston moves inward, driving out the burnt gases through the exhaust valve. Inlet valve is closed.

As the fuel is injected under pressure at the instant of maximum compression (same as in Diesel engines), this method is called the "semi-Diesel" principle of operation. It is called *semi-Diesel* because the compression (150 to 300 lb.) is considerably lower than in Diesel engines (500 lb. compression), so that the heat of compression must be assisted by the heat from the hot bulb in firing the fuel.

Two-stroke Cycle Principle of Operation, as employed by *two-stroke cycle semi-Diesel Engines* (Fig. 191).—All moving parts of the engine are enclosed in a crank chamber fitted with large air-inlet valves.

Stroke 1 (Compression).—The rising piston covers the air port and the exhaust port. The air which has filled the cylinder is compressed to a pressure from 150 to 300 lb. pressure per square inch. *This is the compression stroke.*

During the upward movement of the piston, air is sucked into the enclosed crank chamber through the air valves.

Stroke 2 (Power).—When the piston is near the top of its stroke, fuel is injected through the spray nozzle into the hot bulb. The atomized fuel is ignited and burned by the heated compressed air and the hot bulb, and the high pressure developed forces the piston downward. Shortly before reaching the bottom of its stroke the piston uncovers the exhaust port through which the burned gases escape; later the air port is uncovered, allowing compressed air from the crank chamber to enter the cylinder, driving out the burned gases, and filling the cylinder with clean air. *This is the power stroke.*

While the piston is moving downward, it is compressing the air in the enclosed crank chamber, the air valves being closed.

Thus the cycle consists of two strokes (one idle stroke followed by one power stroke).

Cooling.—Oil engines are cooled in a similar manner to gas engines except that a number of small, low-compression oil engines, used for agricultural purposes, have no cooling-water *circulation.* The cooling-water jacket is open at the top, forming a hopper containing a fair quantity of water, which during operation of the engine heats up and boils. Marine oil engines, of course, use sea water for cooling purposes.

Water Injection.—In some engines, it is customary on heavy loads to arrange for a small amount of water's dropping into the

vaporizer or into the air-inlet valve or passage. The water turns into steam and has a softening effect on the character of the explosions, resulting in smoother running of the engine. It also enables higher compression to be carried.

Fuel.—Fuels used in oil engines are kerosene, gas oil, and black fuel oil (often referred to as "crude oil").

Kerosene is the fuel used mostly in low-compression oil engines and also frequently in semi-Diesel oil engines. It is too heavy to vaporize properly in most carbureters but will do so satisfactorily in the hot bulb. If the heat of the hot bulb is much above a faint red heat, the kerosene decomposes and forms soot; if much below, the kerosene does not vaporize properly.

Keeping the temperature of the hot bulb uniform is consequently of the greatest importance. In some oil engines an adjustable portion of the exhaust gases is carried around the vaporizer, which makes its possible to regulate the temperature of the hot bulb as required to suit the load. Advancing or retarding the ignition according to the load also helps to regulate the hot-bulb temperature.

When the work done by the engine varies considerably, the hot bulb will generally get too hot on a heavy load and too cold on a light one.

Gas Oil.—Gas oils constitute the principal fuels used in semi-Diesel oil engines. The hot bulb must be slightly warmer with gas oils than with kerosene, as gas oils are not so easily vaporized.

Black fuel oil is generally the residuum from crude petroleum after all gasoline and kerosene have been distilled off. It may also be a mixture of heavy petroleum residual oils and gas oil. Black fuel oils are largely used in semi-Diesel oil engines.

Uniform Fuel.—When the engine has been carefully adjusted to suit a particular class of fuel, it is very important that the fuel supplies should be as uniform in quality as possible, in order to obtain highest efficiency and to obviate the necessity of further adjustment; otherwise, incomplete combustion will take place and will interfere with lubrication.

METHODS OF LUBRICATION

Horizontal oil engines and semi-Diesel engines are lubricated in exactly the same way as horizontal small or medium-size gas engines, the oil being distributed from separate lubricators or from a mechanically operated lubricator to all points.

Vertical oil engines, because of the high speed at which they operate, have the working parts enclosed in a crank chamber and employ the following methods of lubrication:

1. Splash system of lubrication, similar to vertical gas engines or automobile engines.
2. Force-feed circulation system, similar to vertical automobile engines.
3. Mechanically operated lubricators.

Systems 1 and 2 are fully described under automobile engines and are used only in connection with low-compression four-stroke cycle oil engines.

As the crank chamber is enclosed, the heat radiated from the pistons and cylinder walls is, to a large degree, retained in the crank chamber, so that the oil in the crank chamber gets very warm, the resulting temperature being from 100 to 160°F. If a temperature of 140°F. is greatly exceeded, the life of the oil will be reduced, and it may throw down a dark deposit.

The oil in the crank chamber is always more or less affected by the admixture of fuel, which has not been properly vaporized (and burned) inside the working cylinder but mixes with the oil on the cylinder walls and gradually works down past the piston rings and drops into the crank chamber. The result is that the oil becomes thinner, and its lubricating qualities are greatly affected. It becomes dark in color, owing to black residual or carbonized matters coming down from the pistons, dropping into the crankcase and mixing with the oil.

System 3.—A mechanically operated force-feed lubricator is always used in connection with the two-stroke cycle oil engines or semi-Diesel engines, whether vertical or horizontal. A splash or force-feed system must not be used, as the oil spray would contaminate the air which is drawn through the crank chamber. The lubricator is operated by the engine and feeds oil to the cylinder, crankpin (by a banjo arrangement), gudgeon pin, and sometimes also to the main bearings, which, however, are sometimes ring oiled and occasionally lubricated by grease.

Piston.—The oil is introduced under pressure into the cylinder, usually at two points, one at the front and one at the back, and preferably timed, so that it is injected between the first and second piston rings at the exact moment when the piston is in its lowest position.

Gudgeon or Wrist Pin.—One of the oil feeds from the mechanically operated force-feed lubricator feeds oil through the cylinder wall, so timed as to inject it into the cylinder to a central oil passage in the wrist pin. Figure 192 shows a scoop arrangement now very generally employed.

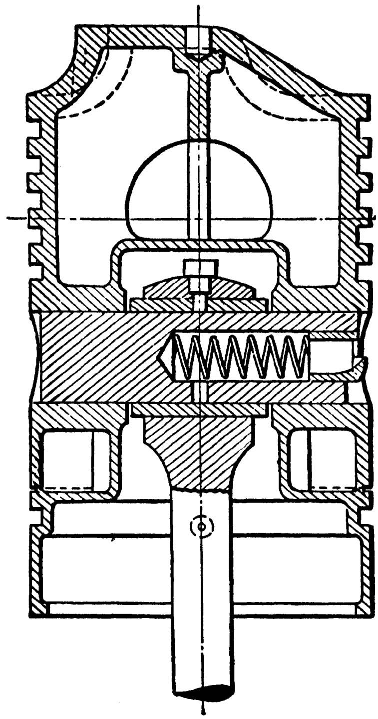


FIG. 192.—Wrist-pin lubrication.

As in two-stroke cycle engines, cold air is constantly drawn through the crankcase; this is kept fairly cool, but there is always the danger of impurities and dirt in the air getting into the working surfaces of the various bearings.

Main Bearings.—Where the main bearings are lubricated with grease, there is considerable loss in power, due to the friction, as the bearing temperature must rise to a point where the grease melts before it starts lubricating.

Leakage of air from the crank chamber must be guarded against, the troublesome places being the main bearings and the exhaust

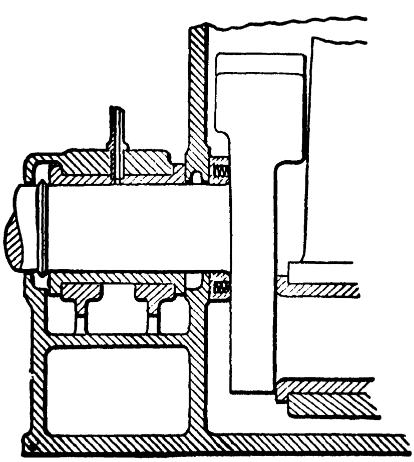


FIG. 193.

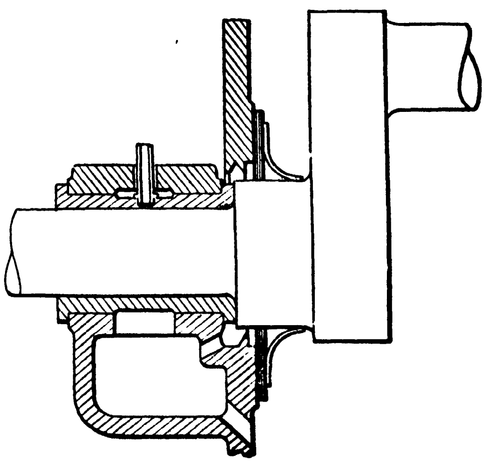


FIG. 194.

port. Figure 193 shows the commonest form for preventing leakage through the main bearings. It consists of a bronze ring

revolving with the shaft, it has a very good sliding fit on the collar and is pressed against a turned face of the crankcase by means of light springs.

Figure 194 shows a simple type, consisting of a leather ring fitting snugly against the shaft and revolving together with a thin brass ring, say 1/8 in. thick, which is forced against the casing by the leather and the air pressure. The leather must be renewed at intervals, as it perishes owing to the action of the lubricating oil.

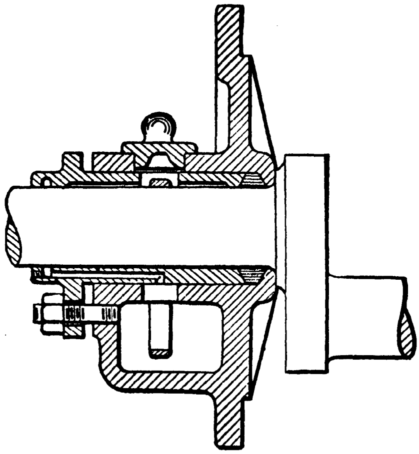


FIG. 195.—Preventing leakage from crank chamber.

Figure 195 shows a design embodying a packed gland.

Leakage of the rings is often due to dirt in the intake air getting between the faces; the grit may often be "washed" out by liberal use of an oil syringe.

Some builders of low-power engines employ grease for main bearing lubrication, the film thus provided being sufficient to prevent air leakage. The grease is applied through Stauffer cups or spring grease cups or, preferably, through compressed-air grease cups like the "Menno." The grease should be of a soft to medium consistency, so as not to increase the friction more than need be.

The feed pipes should have no bends and should be placed at a steep angle, say over 60 deg., so that if the bearings get unduly warm some of the grease in the pipes will melt and run into the bearings on its own accord.

Governor.—Irregular running is sometimes experienced with engines governed on the hit-and-miss principle. The cause is often that governor parts stick, owing to the use of an unsuitable oil. Occasional cleaning with kerosene is therefore desirable, as many of the best oil-engine oils are slightly gumming, and it is not often practicable to use a thin straight mineral oil for the special benefit of the governor.

If the exhaust-valve spindle sticks, a liberal supply of lubricating oil will only aggravate the trouble. Kerosene should be applied and will usually prove effective.

DEPOSITS

Deposits may arise from one or several of the following causes: impurities in the intake air, overfeeding of oil, unsuitable oil, impurities in the fuel, unsuitable fuel, hot bulb too hot or too cold, improper fuel vaporization, incomplete combustion, water injection.

Where, in low-compression oil engines, deposits have developed inside the combustion chamber, they often (and particularly if the water cooling is defective) become incandescent and cause preignitions.

Impure Intake Air.—The same remarks apply as for gas engines (page 480).

Overfeeding of Oil.—Excess oil passing to the cylinders causes carbon deposits to develop behind and between the piston rings, the amount depending upon the quality of the oil.

Unsuitable Oil.—Too low-viscosity oil fails to provide satisfactory lubrication; wear follows, the metallic wearings baking together with charred oil and forming deposits; an increased oil feed will only aggravate the trouble. Too viscous an oil will not spread properly and may thus bring about similar results.

Impurities in Heavy Fuel Oils.—When the fuel oil contains too much free carbon and ash, the unburned impurities will deposit themselves on the cylinder walls. They will adhere to the lubricating oil and form a deposit, causing heavy wear of cylinder walls and piston rings.

Unsuitable Fuel.—A fuel containing too much asphalt or being too thick to flow readily will not be properly atomized and does not burn completely during combustion. The unburned portions will accumulate on the piston top, behind and between the piston rings, etc., and form carbonaceous deposits.

Hot-bulb Temperatures.—The hot-bulb temperature may become too high, owing usually to heavy engine loads. This high temperature causes cracking of the oil particles when they meet the highly heated wall of the hot bulb, and the combined effect of the high temperature and pressure prevailing is to gasify the fuel and at the same time decompose it to a great extent. The splitting up of the heavy hydrocarbons into light hydrocarbons always throws out a certain amount of carbon in

the form of coke, which accumulates in the hot bulb and, when it reaches the cylinder, interferes with lubrication.

Too low a temperature of the hot bulb is frequently experienced under light-load conditions, and the result is that when the fuel particles reach the wall of the hot bulb they become only partly gasified and some of the heaviest hydrocarbons in the fuel leave a bituminous residue of a sticky nature which is bound to reach the piston and piston rings and is very objectionable. When the engine becomes cold these sticky deposits solidify like glue, and many cases have been known where it has been almost impossible to move the piston once the engine has cooled down.

For each class of fuel, whether kerosene, gas oil, or black fuel oil, there is a certain range of hot-bulb temperature within which the fuel will be completely gasified without leaving any appreciable residue in the hot bulb. It is obviously desirable that this range of temperature should be as wide as possible.

Improper fuel vaporization is apt to take place where the fuel is fed by gravity through the air-inlet valve, as, owing to the fact that the fuel is not heated, the inrushing air does not afford sufficient means for breaking it up and atomizing it; the results are similar to those under light-load conditions with the vaporizer too cold.

Incomplete combustion is due chiefly to bad atomization but may also be due to the vaporizer's being too cold or to faulty timing of the valves. When the spray is coarse, owing to the fuel's being too viscous or to the fuel valve's being out of order or to too low fuel pressure, etc., the combustion of the fuel charge becomes incomplete; *i.e.*, some particles of the fuel are so big that they burn only on their surfaces—they are charred. The result is that, during the power stroke and the exhaust stroke, the cylinder is full of dense black smoke (black exhaust) which blackens and contaminates the oil film on the cylinder walls.

A finely atomized spray is, therefore, very necessary if lubrication troubles are to be avoided, and in many engines unsatisfactory atomization and incomplete combustion are often unavoidable under light-load conditions.

Water Injection.—In some engines, particularly marine engines, it is customary to arrange for a small amount of water to drop into the vaporizer or into the air-inlet valve or passage. The water turns into steam and has a softening effect on the character

of the explosion, resulting in smoother running of the engine on heavy loads. The "water drips" should be used only under heavy loads. If used under light-load conditions, or if used in excess, the water will not evaporate completely; it will tend to wash away the oil film and destroy lubrication, resulting in heavy wear and carbonaceous deposits. In enclosed engines oiled by the splash or force-feed circulation system, excess water will reach the crank chamber and, mixing with the oil, cause trouble through emulsification.

The water, unless it is distilled water, contains a certain amount of salts which are deposited inside the engine when the water evaporates and act like grit between the piston rings and cylinder walls.

SELECTION OF OIL

In order to select the correct oil for an oil engine, it is necessary to consider the piston clearance, the piston rings (their number and whether they are pegged or not), the temperature of the water jacket, the method of lubrication, whether the combustion is clean or otherwise, etc. A few of these points are considered in the following.

Piston and Piston Rings.—By far the largest amount of friction is between the piston, piston rings, and cylinder walls. Nothing is therefore so important as the satisfactory and efficient lubrication of the piston.

It is important that the piston clearance should not be excessive. In some of the early types of semi-Diesel engines the piston clearance is large and tends to bring about "piston rocking," necessitating the use of exceedingly viscous lubricating oils to prevent the explosion gases from blowing past the piston.

Some semi-Diesel engine manufacturers are still recommending oils as viscous as steam-cylinder oils for piston lubrication, and the result, as might be anticipated, is that besides an excessive amount of power consumed by piston friction there is excessive wear of the piston rings and cylinder walls. Such viscous oils aggravate troubles with deposits from whatever source they may arise.

If friction is to be reduced to the minimum, the piston clearance must be sufficient only to allow easy sliding motion of the piston

under conditions of heavy load, and the piston rings should be slightly softer than the liner and pegged, so that they will wear to a fit with the shape of the cylinder.

This "pegging" of the rings is most essential. Each piston ring should be numbered and always put back in the same groove after examination. If piston rings are not pegged, they move in their grooves, and the gaps may easily work into line, with the result that the explosion gases blow past the piston, charring the lubricating oil and causing excessive wear.

The piston rings should be a good fit in their grooves; they act like valves, being bright on their bottom surface and dull on their top surface. If the outer surface of the rings in contact with the cylinder wall is dull, the dullness indicates leakage past the ring during operation. If piston clearances are normal, and piston rings of the right material and pegged, it is possible to use medium-viscosity lubricating oils, and the piston friction will be found to be very reasonable. Where the piston rings are not "pegged," a very heavy-bodied oil is occasionally used, in order to seal the piston and prevent too much oil from passing the piston rings.

Combustion.—When clean combustion is maintained, straight mineral oils often give satisfactory results. But when carbon deposit is formed inside the engine, owing to the hot-bulb temperature's being too high or too low or to incomplete atomization of the fuel or to unsuitable fuel, etc., such deposits will ordinarily accumulate and clog the piston rings, making them inflexible in their grooves, with the result that they no longer keep compression- or explosion-tight, and heavy friction and wear immediately follow.

Experience has, however, proved that even extreme cases of carbonization of the nature just referred to have been cured by using castor oil, rape oil, olive oil, lard oil, or mixtures of such oils with mineral oil in various proportions.

All fixed oils, *i.e.*, vegetable oils and animal oils, contain a fair proportion of oxygen, and in all probability this oxygen during the explosion period assists in burning away the carbonaceous deposit.

The effect of the compound is to prevent deposits from baking together and forming a crust. The little globules of compound mixed with the mineral oil burn away clean and continuously

break up the deposits, so that they may be swept out with the exhaust or work their way past the piston to the outside.

We know that many vegetable oils are much more inclined to produce gumminess exposed to the air than animal oils, so that animal oils should generally be preferred for mixing with mineral oil, the percentage of animal oil required being entirely dependent on the degree of carbonization taking place inside the engine.

Speaking generally, an admixture of from 6 to 15 per cent of lard oil to a mineral oil of suitable characteristics will give clean lubrication in all normal cases.

Water Injection.—Many marine semi-Diesel engines are in the hands of fishermen and others who are not particularly conversant with the working of the engines, with the result that the engines get scant attention generally. As regards the water injection, it is generally kept on whether the engine is on a heavy or a light load. The result is that the internal lubrication becomes very poor unless compounded lubricating oils are used. Pure mineral oils are simply washed away from the piston, rusting of parts and heavy friction and wear being the unavoidable result. The excess water also contaminates the bearing oil; but when the bearing oil is compounded it emulsifies with the water, and the bearings may be quite satisfactorily lubricated, the only drawback being that the emulsified oil collecting in the base of the engine cannot be filtered and used afresh.

For oil engines in which the combustion is not clean, or where water injection is employed, compounded oils are therefore essential to satisfactory lubrication, while for oil engines with clean combustion and without water injection, straight mineral oils may be used.

For obvious reasons, compounded oils are not so satisfactory as straight mineral oils in force-feed circulation oiling systems; if a compounded oil is needed because of the cylinder requirements, a nondrying fixed oil should be used for compounding and as small a percentage as possible.

Oil Consumption.—Oil engines are frequently extravagantly lubricated, either because of the lubricators or because it is not possible to give the engines the necessary close attention. Excessive oil consumption means, however, not only waste of oil but also increased tendency to form carbon deposit, so that oils

having "noncarbonizing" properties will be given a decided preference in most cases where overfeeding takes place.

These remarks apply particularly to marine oil engines and semi-Diesel land engines.

Whereas the consumption of oil in horizontal oil engines is very similar to the oil consumption of small and medium-size horizontal gas engines (page 492), that of other oil engines may be anything from 50 to 100 per cent higher, depending upon circumstances.

For lubrication of oil engines, oils similar in viscosity and general characteristics to gas-engine oils 2c, 3c, and 4c[1] are required, but they are here referred to as "oil-engine" oils.

The oils should be compounded with 6 to 15 per cent of non-drying fixed oil unless for special reasons, such as having to use

LUBRICATION CHART
For Kerosene-oil Engines and Semi-diesel Engines

Type of engine	Horse-power per cylinder	Oil-engine oil	Viscosity in centipoises at 50°C.	Percentage compound required
Low-compression oil engines:				
a. Open types,* nearly always horizontal................	Up to 50	No. 2c	8	Up to 15
b. Enclosed types, nearly always vertical.............	Above 50	No. 3c	10	Up to 15
Employing splash-oiling system		No. 2c or No. 3c	8 or 10	Less than 10
Employing force-feed oiling system		No. 3c or No. 4c	10 or 13	Less than 10
Semi-Diesel engines, whether vertical or horizontal......	Up to 50	3c	10	Usually less than 10
	Above 50	4c	13	Usually less than 10

* In such rare cases, where very excessive carbonization and gumming takes place, the engine is either badly designed or adjusted or out of order, or the operating conditions are very exceptional, *e.g.*, long periods of light-load operation. Under such conditions pure castor, lard, rape, olive, etc., may be used temporarily and will give clean or comparatively clean, lubrication, but such oils are expensive and usually have other drawbacks, causing gumming or corrosion.

[1] See p. 495.

the oil-engine oil also on other machinery for which a compounded oil is considered unsatisfactory, it is preferred to use the oil without the admixture of fixed oil.

Some white bearing metals, rich in lead, are quickly attacked by free fatty acid in the oil and may for this reason demand the use of a straight mineral oil.

In the lubrication chart for oil engines and semi-Diesel engines given on page 544, oil engine oils 2c, 3c, and 4c are recommended. The numbers 2, 3, and 4 refer to the viscosity number of the oil (see page 57); the letter *c* indicates that the oils are compounded with fixed oil.

CHAPTER XXXII

DIESEL ENGINES, LAND AND MARINE

Diesel engines may be classified as follows:

Type of Diesel engine	Number of cylinders	Horsepower per cylinder	R.p.m.
Four-stroke cycle (practically all single acting)	1 to 12	10 to 750	2,500 to 120
Two-stroke cycle			
a. Single acting	2 to 12	15 to 650	1,250 to 120
b. Double acting	4 to 12	200 to 2,750	450 to 100

Land Diesel Engines.—Practically all land Diesel engines are of vertical construction; only a few, notably in Germany, are of horizontal make.

Land Diesel engines are used for a variety of purposes, such as driving electric generators in electrical power stations, large works, or mills.

Recently there has been a large development of Diesel engines for locomotives (combined with electric generators) and for automobile purposes (*e.g.*, motor trucks).

Marine Diesel Engines.—All marine Diesel engines are vertical.

Slow-speed marine Diesel engines are used as main engines in the merchant-marine service for ship propulsion and are usually reversible. A few ships have been built with nonreversible Diesel engines, either driving electric generators which produce current for operating slow-speed electric motors driving the propeller direct or driving centrifugal pumps supplying water under pressure to "Foettinger" transformers, which can be made to rotate in either direction and at variable speeds, driving the propellers direct.

The auxiliary machinery, such as pumps, winches, steering gear, etc., on board a Diesel motor ship is operated electrically, by steam, hydraulically, or by compressed air.

High-speed marine Diesel engines are used as main engines in torpedo boats, submarines, small coasters, yachts, launches, etc., and in other cases as auxiliary engines, *e.g.*, electric-generator engines, where limited weight and space are of primary consideration.

Special-type Diesel Engines.—*The Junker Diesel engine*, often called the "double-piston" engine, is a special type embodying the two-stroke cycle principle, with two opposed pistons in each cylinder.

Solid-injection Diesel engines dispense with the air compressor and inject the fuel under an enormous pressure—4,000 lb. per square inch—atomizing it mechanically. These engines are used largely for submarines.

CONSTRUCTIONAL POINTS

The main engines aboard a Diesel ship are always of the crosshead type, with the external parts partly or entirely enclosed.

With trunk-piston engines, wear of the thrust collars on the propeller shaft would cause trouble with pistons but does not affect the flat crosshead guides in crosshead-type engines. Quite apart from this consideration, there is a growing tendency to construct all Diesel engines, land and marine, except those developing 50 hp. or less per cylinder, as crosshead-type engines, because there is less trouble with piston distortion, and the crosshead bearing can be kept cool, being remote from the piston; carbonized dirty oil from the piston may be prevented from reaching the crank chamber, and the oil in the crank chamber can be prevented from reaching the cylinders; it is kept cooler and cleaner and therefore retains its vitality much longer.

Most auxiliary Diesel engines and other high-speed engines are of the trunk-piston type and of necessity always entirely enclosed. The pistons, when above, say, 18 in. in diameter, are always built in two parts, a plate being inserted between the top and the bottom portion, which prevents oil from the gudgeon pin from splashing into the hot, hollow piston head, where it would burn and char.

Two-stroke cycle engines are more difficult to lubricate than four-stroke engines. The pressure is never relieved on the moving parts, making it difficult for the oil to get in between the

bearing surfaces. The long trunk pistons needed to close the scavenging and exhaust ports have large friction surfaces and are more liable to wear and seizure than the pistons in crosshead-type engines. Two-stroke engines may be constructed with crossheads, but it makes a very tall engine, as the long trunk pistons must be retained.

Piston rings number from four to six and should not be too near the top of the piston, as they then invariably stick. It is becoming general practice to leave the upper 25 per cent of the piston without rings.

Piston rings and grooves should be accurately made and with as small clearance as experience proves permissible; axial clearance may be made 1 per cent of the thickness of the ring; radial clearance must also be small to counteract oil passing behind the rings.

When fitting old pistons with oversize rings, the clearance may be reduced, because one is now assured that the pistons undergo no more deformation when in operation.

The straight-cut bevel joint still appears to be most favored, but makers do not always peg the rings, which undoubtedly is an advantage (see page 502).

The ring-joint clearance may be made 0.0035 to 0.005 in. per 1 in. of piston diameter, for four-stroke and two-stroke engines, respectively.

As regards scraper rings for trunk-piston engines, see page 499.

W. G. G. Godron, Socony-Vacuum Corporation, New York, has proposed some interesting improvements in Diesel piston-ring design, based on the following lines of thought:

During the operation of a Diesel engine, three distinct pressure conditions interfere with effective lubrication, *viz.:*

1. High gas pressure above each piston ring, acting on the upper surface of the ring and thus pressing the lower surface with tremendous force against the oil film which coats the lower side of the groove.

2. High gas pressure behind each ring, forcing the face of the ring against the oil film on the cylinder wall.

3. Excessive difference between the pressure above and that below a given ring (particularly the topmost ring). The magnitude of this difference determines the magnitude of the effect of the pressures referred to in 1 and 2.

Figure 196 shows the downward forces acting on the top ring. The maximum gas pressure behind the ring (in the annular space *B*) can be equivalent only to the maximum pressure in the cylinder, *viz.*, 700 lb. per square inch. This pressure may be considered as acting upon the lower surface of the ring at the point *C*, *i.e.*, its inner edge. Draw the line *CD* to represent this inner pressure.

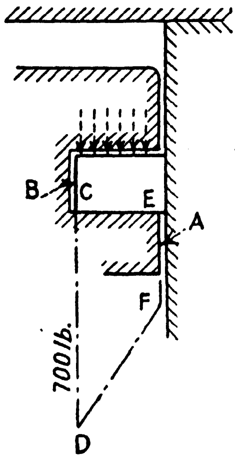


Fig. 196.

The magnitude of the pressure below the ring (in the annular space *A*) depends, of course, upon the amount of leakage across the face of the ring (in contact with the cylinder wall) and across the lower surface (in contact with the ring groove). Experiments to determine the maximum gas pressure in the annular space *A* have indicated that this pressure is less than half that above the ring (in this case, say 300 lb. per square inch). This pressure may be considered as acting on the lower surface of the ring at the point *E* (its outer edge). Draw the line *EF* to represent this outer pressure.

The line *DF* represents the pressure drop across the lower surface of the ring which is in contact with the side of the groove.

Godron suggests (Figs. 197 and 198) cutting an annular groove *A* in the lower surface of the ring and terminating this groove just short of the split in the ring. Radial grooves *B* connect *A* with the space at the back of the ring so that the pressure building up in *A* now will counteract that above the ring, forcing it downward, and thereby reduce the pressure by about 75 per cent.

To facilitate the pressure's getting behind the ring, the radial grooves *C* (Fig. 199) are cut across its entire upper surface. These grooves assure speedy admission of pressure behind and below the ring and thus avoid high momentary frictional resistance during the later portion of the compression stroke and the early part of the power stroke.

Figure 200 shows Godron's proposal to counterbalance to a certain extent the pressure that forces the ring against the cylinder wall, by having vertical passages *P* allow pressure to build up in the circumferential groove *G*.

Ordinarily, the greater portion of the load is taken by the two top rings and particularly by the top ring.

Godron suggests distributing the load over a larger number of rings by making the piston and rings act as a labyrinth packing. He accomplishes this by permitting the upper rings to leak without damaging the oil film between rings and wall. Each ring steps the high gas pressure down a suitable amount, until the

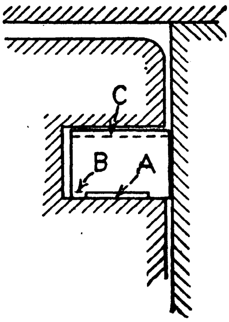


Fig. 197.

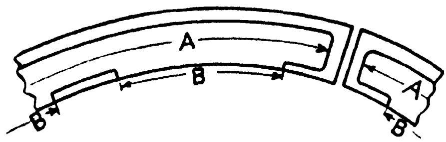


Fig. 198.

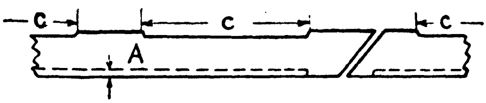


Fig. 199.

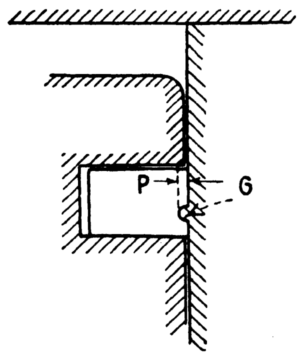


Fig. 200.

FIGS. 197–200.—Godron's suggested piston-ring improvements.

pressure at the lower rings theoretically is atmospheric, and "blow-past" thus avoided.

Figures 201 and 202 show how this is done. The radial grooves *MN* permit a predetermined leakage past the outer sealing area of the lower ring surface, thus increasing the counterbalancing pressure in the annular space below the ring and decreasing frictional resistance of the ring movement in its groove. A smaller number of similar grooves are cut in the lower surface of the second ring, a still smaller number in the third ring, and so on.

The beneficial effect can be appreciated by comparing the equalized pressures obtained with a set of grooved rings (Fig. 203)

with the unequalized pressures obtained with ordinary snap rings (Fig. 204).

Cooling.—The piston head in larger engines is frequently built with provision made for cooling, the cooling medium being either oil or fresh water. The cooling water for the pistons must be fresh water; sea water is liable to deposit salt incrustations inside the pistons. In navigating in muddy or shallow waters, it is obvious that such water is totally unsuitable for piston-cooling purposes. It is bad enough for the cylinder jackets and for cooling the piston-cooling water; and as incrustations, scale, or mud greatly reduce the heat transmission, all cooling spaces must be so designed that they can be easily examined and cleaned, say, every 3 months.

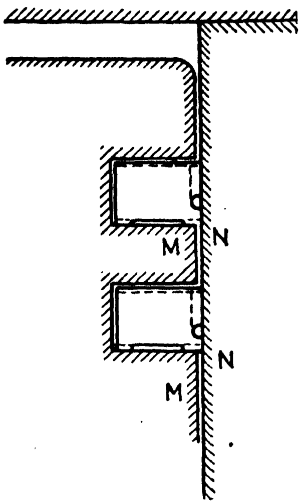


Fig. 201.

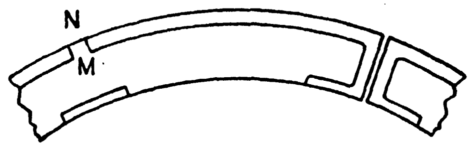


Fig. 202.

FIGS. 201–202.—Godron's suggestion for distributing load over all piston rings.

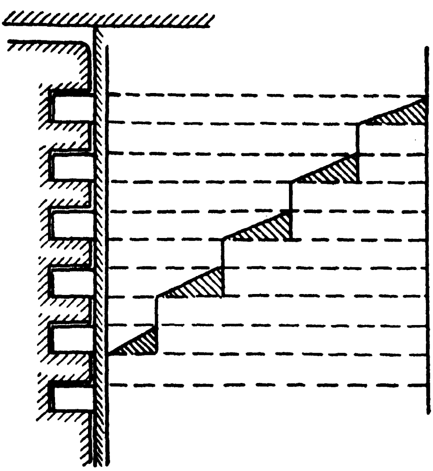


FIG. 203.—Equalized piston-ring pressure.

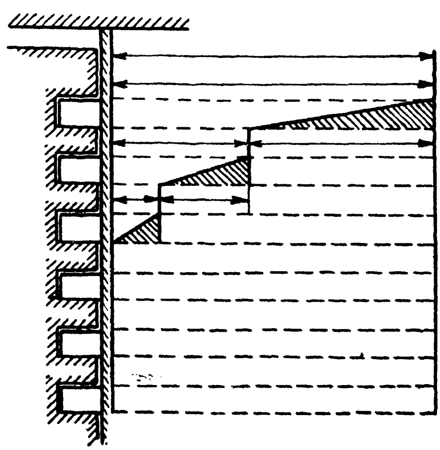


FIG. 204.—Unequalized piston-ring pressure.

In shutting down the engine, cooling of the pistons and cylinders must be continued for ½ hr. to prevent boiling of the

water and formation of deposits of salt, lime, etc. This is particularly important where hard water or sea water is used and also with piston-cooling oil in marine Diesel engines, as the oil is cooled by sea water, and it is not always possible to guard against leakage of a little sea water into the cooling oil. Leakage from the joints or telescopic pipes carrying water or oil into the piston is difficult—almost impossible—to avoid. If cooling water gets into the oil, it may cause emulsification in the same way as water in turbine oil. Leakage of cooling oil into the lubricating-oil system is not so serious; but if cooling oil is very thin, it may in time reduce the viscosity of the lubricating oil sufficiently to be noticeable.

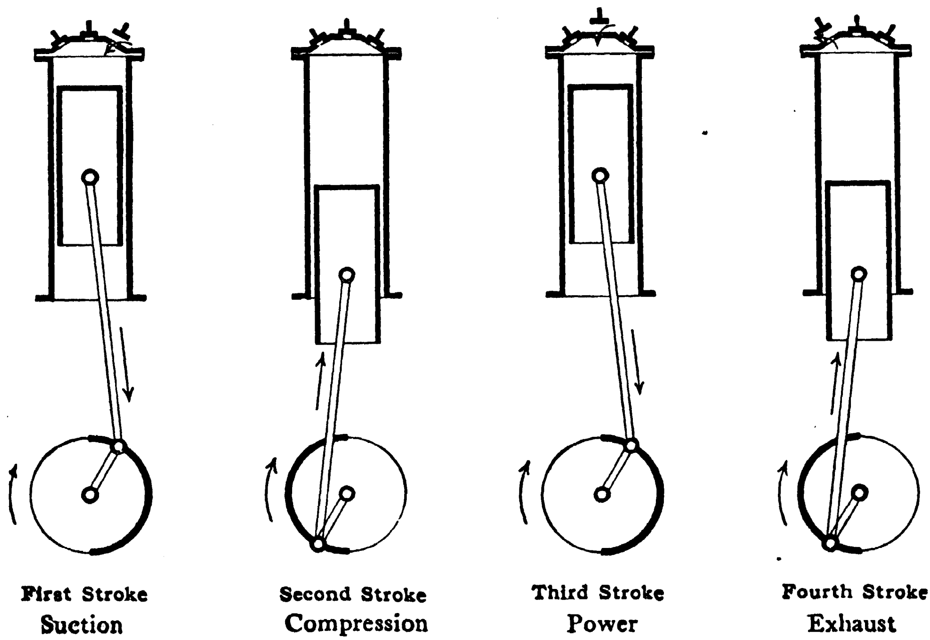


FIG. 205.—Four-stroke cycle principle of operation, Diesel engines.

PRINCIPLE OF OPERATION OF DIESEL ENGINES

In the Diesel engine fuel is injected into the cylinder and is converted directly into power. It operates on either the four-stroke or the two-stroke cycle principle, as follows:

Four-stroke Cycle (Fig. 205).

Stroke 1 (Suction).—The piston moves downward away from the cylinder head, sucking in air through the open air-inlet valve. Exhaust valve and fuel valve are closed.

Stroke 2 (Compression).—The piston moving upward toward the cylinder head compresses the air to a pressure of about 500 lb., resulting in a temperature of about 1000°F., which is sufficient to ignite and burn the fuel.

Air-inlet valve, exhaust valve, and fuel valve are closed.

Stroke 3 (Power).—The fuel valve opens; fuel is blown in the form of a fine spray into the cylinder by means of the highly compressed air coming from the air reservoirs. There is no explosion, but the fuel, owing to the high temperature existing in the cylinder, burns completely as it enters, maintaining a constant pressure during fuel injection. The fuel valve is

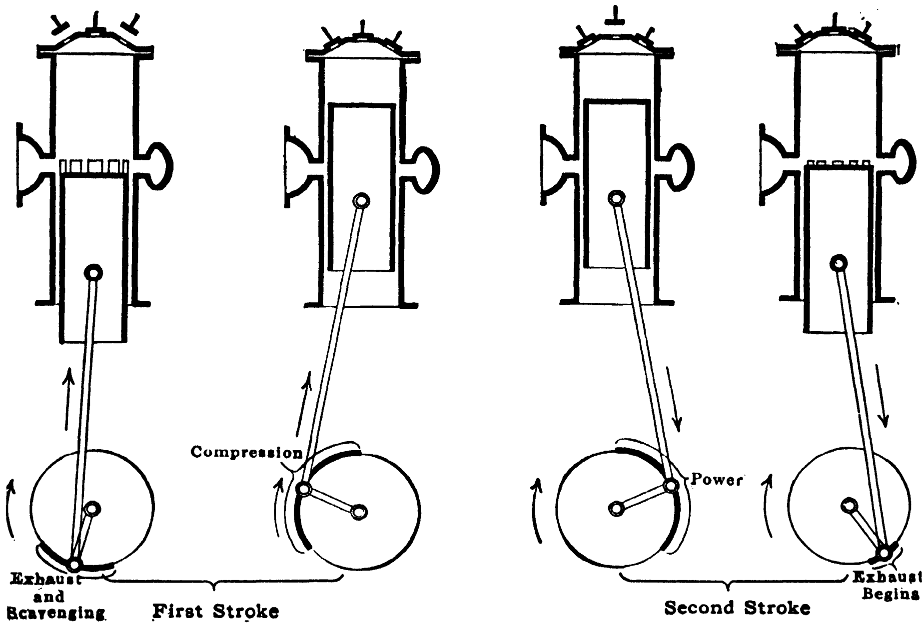


FIG. 206.—Two-stroke cycle principle of operation, Diesel engines.

then closed; the expanding gases force the piston away from the cylinder cover during the power stroke, all valves being closed.

Stroke 4 (Exhaust).—The piston, moving upward toward the cylinder cover, drives out the burned gases through the open exhaust valve. Air-inlet valve and fuel valve are closed.

Thus four strokes of the piston, *i.e.*, one power stroke followed by three idle strokes, complete the cycle of events.

Two-stroke Cycle (Fig. 206).

Stroke 1 (Compression).—At the beginning of the stroke, the piston has uncovered the exhaust ports through which the burned gases are expelled, the scavenging air entering either through the scavenging valves in the cylinder cover or through the scavenging ports in the cylinder; the piston, rising, covers the exhaust ports. The scavenging valve or ports are closed, and the air is compressed to a pressure of about 500 lb.

Stroke 2 (Power).—At the top of the piston stroke, fuel is sprayed into the cylinder, and the piston descends on its power stroke.

Toward the end of the stroke the piston uncovers the exhaust ports, and the exhaust gases escape, being assisted by the scavenging air blown into the cylinder through the scavenging valves or ports.

Thus two strokes of the piston, *i.e.*, a compression stroke followed by a power stroke, complete the cycle of events.

Starting.—The Diesel engine is always started by means of compressed air. The starting-air reservoirs are filled with compressed air, usually at a pressure of 350 lb.; occasionally higher pressures are employed. This pressure should never fall as low as 200 lb. Starting air either is delivered to the starting-air reservoirs from an auxiliary air compressor, or it is taken from the injection-air bottles. A pipe conveys the air from the starting-air storage bottle to the starting-valve casings. The starting valves in all cylinders are automatically opened and closed, so that the starting air is admitted only into those cylinders in which the pistons are in the right position for their downward strokes.

When the engine has made a few revolutions by means of compressed air, the fuel pump is put into service. The starting handle, which throws the fuel pump into automatic service, throws the starting-air valves out of service.

In the case of two-stroke cycle engines, starting is occasionally performed by admitting compressed air into the scavenging-pump cylinders. The resultant motion of the scavenging pump is transmitted through levers to the main engine crosshead.

Reversing.—For the purpose of reversing marine engines, two sets of cams are employed: "ahead cams" and "astern cams." For going ahead, ahead cams are in action, operating all valves; for going astern, astern cams are put into action, controlling the operation of the valves. The necessary alterations in the position of the camshafts when reversing are carried out by means of compressed air or, in the case of smaller engines, by hand.

FUEL

The fuels in use are:

Gas oil.
Black fuel oil.
Coal-tar oil or lignite-tar oil.
Coal tar.
Vegetable oils and animal oils.

Gas Oil.—Gas oils are excellent fuels for Diesel engines but are more expensive than black fuel oils.

Black Fuel Oil.—Fuel oils (see page 539) for Diesel purposes must not be too viscous; if they are too viscous at the temperature prevailing in the fuel-valve space, they are badly atomized. Fuel oils of a Saybolt viscosity, say less than 200 sec. at 104°F., will normally be found to atomize readily.

Coal-tar oil and lignite-tar oil are produced from bituminous coal and lignite, respectively, the distillation being directed with a view to producing a suitable quality of tar oil for Diesel engines. Usually, a small percentage of gas oil or other light petroleum-fuel oil is injected into the Diesel-engine cylinder by an ignition oil pump, just before the tar oil is sprayed in by means of the fuel pump. The burning gas oil helps to ignite the atomized tar oil, so that it burns completely without "sooting."

Coal tar when produced from bituminous coal in vertical retorts can sometimes be used, but it must be heated in order to flow freely and can be employed only with the addition of about 10 per cent of light petroleum-fuel oil used in the same manner as described under "Tar Oil."

Vegetable and animal oils, such as castor oil, palm oil, earthnut oil, cottonseed oil, and whale oil, can also be used as fuel in Diesel engines and may come into consideration for tropical countries where there is no easy access to other fuels.

Fuel Storage, Etc.—When the fuel is pumped from the storage tanks it should be carefully strained before entering the daily supply tanks. The latter are fitted with a drainpipe for removing water which may accumulate. The fuel delivery is taken from the daily supply tank at a height of, say, 10 in. above the bottom, so that only clean fuel passes down through this pipe and through an additional filter to the fuel pump.

Heavy fuel oil is now often freed from its fine impurities by centrifugal purification, because experience has proved that it is just these very fine particles that give rise to cylinder wear attributed to the fuel. Centrifuging the fuel oil twice is an extra assurance of low wear due to this cause.

The best fuel-oil filters would undoubtedly be streamline filters, as they remove even the finest impurities completely; but, so far, their use as fuel-oil purifiers appears to be confined to land Diesel-

engine installations. One difficulty appears to be that water in the fuel makes the streamline filters inactive, saturating the filter pads with water.

When the engine has been carefully adjusted to suit a particular class of fuel, it is very important that the fuel supplies should be as uniform in quality as possible, in order to obtain highest efficiency and to obviate the necessity of further adjustment; otherwise, incomplete combustion will take place and will interfere with lubrication.

METHODS OF LUBRICATION

Trunk-piston, enclosed-type Diesel engines, land and marine, are always lubricated by a full force-feed circulation system, the oil being circulated under a pressure of up to 25 lb. per square inch, depending upon the size of the engine.

Trunk-piston, open-type land engines have all parts lubricated from mechanically operated lubricators, except the main bearings, which are always ring oiled.

Crosshead-type Diesel Engines, Land and Marine.—The *piston lubrication* is always by means of a *mechanically operated lubricator.*

The external parts are lubricated by means of:

1. *Force-feed circulation,* all parts enclosed. Most marine engines (Burmeister and Wain type) employ this system.

2. *Oil distribution by gravity feed* or *by mechanically operated lubricators* to all parts. Most large two-stroke cycle Diesel engines employ these systems; also some four-stroke cycle marine engines.

Piston Lubrication.—The oil feeds from the mechanical lubricator should preferably be timed to inject the oil at the right moment. It is often convenient to have the lubricators arranged for a rotary drive, the cams or levers inside the lubricator being so placed as to operate their respective plungers at the right moment for their respective pistons.

One method which is much used is to have one lubricator for each cylinder unit, all pumps operate simultaneously by means of an oscillating lever, actuated by a cam on the camshaft or by some other part having a reciprocating motion.

For pistons up to 20 to 22 in. in diameter, two separate oil feeds, one at the front and one at the back, are sufficient; for

larger pistons four or six oil inlets are preferred, all separately controlled.

Figure 207 shows an oil injector for timed injection of the oil through a *small hole* on to the piston. With a large oil hole it is obviously not possible to get a satisfactory timing effect.

Force-feed Circulation (referring to all types of engines employing this system).—The strainers for the oil should be in duplicate. When one of them is removed for examination or cleaning, the oil-pump connection from that particular strainer should be automatically closed by a spring-loaded valve, which is pushed open again when the strainer is put back in position.

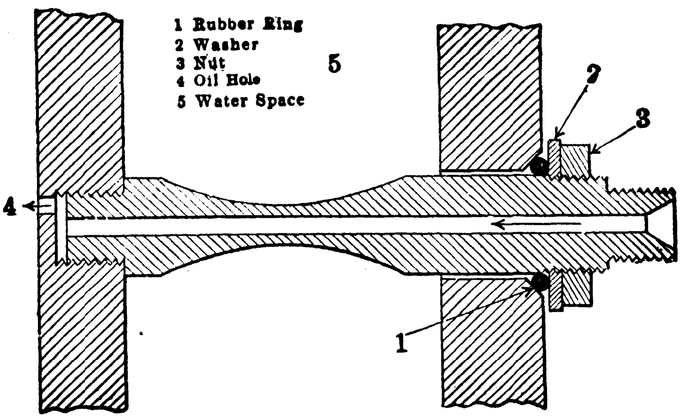


FIG. 207.—Oil injector.

Some makers install a filter—filter pads, sand filters, etc.—somewhere in the circuit. They are of doubtful value as regards extracting carbon particles and may absorb a great deal of power.

With a Diesel engine, as with all internal-combustion engines, the bearings are subject to full pressure almost from the starting moment. A hand pump should therefore be provided to prime the oil pipes before starting the engine. Many bearing troubles are caused by injury done to the surfaces, due to absence of oil in the bearings when the engine is started up before the oil pipes are primed.

Oil Temperature.—Heat radiated from the pistons and cylinder walls is, to a large degree, retained in the enclosed crank chamber, so that the oil in the crank chamber becomes very warm, the resulting temperature being from 100 to 160°F. If a temperature of 140°F. be greatly exceeded, the life of the oil will be much reduced, and it may oxidize and throw down a dark deposit.

In large marine Diesel engines in merchant-marine service, the quantity of oil in circulation is large, being about 1 gal. per horsepower. For this reason, special cooling of the oil is not always needed, particularly as the engine-room temperature is low as compared with the temperature in the engine room of a steamship, where the hot steam cylinders and pipes radiate much heat.

In naval craft, such as submarines, owing to the limited space, the Diesel engines are very compactly designed, all parts being cut down in weight to the minimum. This fact, combined with the high speed of revolutions and the relatively high temperature of the engine room, produces high oil temperature and makes it imperative to provide for adequate and efficient cooling of the oil in circulation.

Centrifugal Purification.—A centrifugal oil purifier (see page 598) is now considered a necessary auxiliary for all Diesel-engine installations of any size, both for heavy fuel oil and for piston-cooling oil.

By no other method can the oil be kept continuously free from carbon, fine metallic particles, rust, water, and other impurities, the result being that the entire system of oil pipes, oil inlets, etc., and the interior of the engine are kept free from dirt and sludge at all times.

This not only saves oil and labor but means, first of all, an increased margin of safety in operating the engine and minimum wear of all parts.

Should, by chance, water enter the system, the purifier will remove it before it gets time to do any damage to the oil or to the engine.

In one case which came to the author's notice, the piston-cooling oil was not purified by centrifugal purifiers, and as the oil temperature was high, and salt water leaked into the oil, heavy oxidation took place (resulting in extreme darkening of the oil, increased viscosity, and the formation of much petroleum acid and tarry deposits) and corrosion. After employing centrifugal purifiers, the corrosion and other troubles were arrested and gradually disappeared, owing, in part, to the continuous addition of fresh oil.

The first batch of circulating oil should always be removed after the first voyage, as the purifiers can often only with diffi-

culty cope with the many initial mechanical impurities emanating from the entire system. With a subsequent fresh charge of oil, the purifiers will ordinarily keep the oil in good condition.

Batch Purification.—For small and medium-size open-type Diesel engines, the waste oil may be collected in tanks, put through the purifier in batches, and the purified oil used over again.

Continuous Purification.—For Diesel engines employing a circulating-oil system, whether by gravity or by pressure, the purifier is preferably so installed that from 5 to 10 per cent of the actual flow of oil through the engine is by-passed through the purifier.

When installing a centrifugal purifier in a Diesel engine which has been in operation for some time, the bowl will need frequent cleaning the first week or two, until the system has been freed from accumulated dirt and impurities, after which the regular intervals between the necessary cleanings will be much longer.

Crank-chamber Corrosions.—L. J. Le Mesurier and R. Stansfield (in their paper in 1934 before the Institute of Marine Engineers, London) report that corrosions of crankpins and crankhead pins have taken place and have been attributed to the oil which, besides petroleum acids, was found to contain hydrochloric acid and water.

A laboratory investigation proved that the acidity itself did not necessarily cause corrosion but only when the acid water was present as large drops. The large drops were more likely to be ruptured when passing through the bearings, whereas small drops were not ruptured and therefore caused no corrosion, even if the total acidity was high.

This experience shows the desirability of having the circulating oil effectively and continuously purified by centrifugal purifiers which remove the large drops of water.

Crank-chamber corrosion may also be caused by SO_2 being transferred from the cylinders into the crankcase via the trunk pistons or even via the piston-rod gland in crosshead-type engines. Alan Wolf mentions one instance where the piston-rod leakage oil was collected and added to the crankcase. Crankcase and centrifuge bowl corrosion was evident but disappeared when the addition of contaminated oil was stopped.

Distribution of Oil by Gravity or by Mechanical Lubricators.—Two-stroke cycle marine Diesel engines, notably those of German make, have experienced a great deal of trouble with heating and heavy wear of main bearings (bottom halves), crankpin bearings (top halves), and crosshead bearings. One of the main reasons for these troubles has been the use of gravity-feed circulation systems embodying a filtering arrangement that necessitated the use of straight mineral oils. Owing to the severe pressures, very heavy-viscosity oils have had to be employed, which were too viscous to filter properly (cold engine rooms) and were found incapable of withstanding the high unrelieved bearing pressures. As far as the crosshead bearing is concerned, the difficulty is entirely overcome by forcing the oil in between the bearing surfaces by means of a small plunger pump fixed on the crosshead and operated by the swinging motion of the connecting rod. Improved distribution of the oil in the crankpin bearings and main bearings has been obtained by having narrow "flats" on the revolving journals which receive the oil and help to distribute it to the bearing parts under pressure.

The most effective solution of the problem, is, however, to use oils heavily compounded with fixed oil, such as rape oil or blown rape oil, to the extent of 15 to 25 per cent of fixed oil. The mineral base should have a low setting point, so that the compounded oil will combine great oiliness with satisfactory fluidity at all times, even in the cold. An oil of this character will feed more uniformly through gravity-feed or siphon oilers than oils having a higher setting point and viscosity. Such compounded oils cannot very well be used in a circulation system but can be applied in a gravity-feed system or, if great economy is desired, by a mechanically operated lubricator. The oil, when leaving the bearings, is usually run to waste into the bilges.

In the two-stroke marine Diesel engines built in England, compounded engine oils have been used for bearings and have given complete satisfaction. One maker finds that with a compounded engine oil, there is even no need to force the oil into the crosshead bearing by a special pump. The oil wedges itself in between the surfaces without any apparent difficulty. Another point in favor of compounded oil is that if water at any time should be needed to cool a bearing, the water will not wash away

the compounded oil but might easily do so with a straight mineral oil.

Oil Consumption.—The oil consumption of Diesel engines ranges from 0.75 to 5.0 g. per brake horsepower-hour. The lowest oil consumption is obtained with large four-stroke cycle Diesel engines of the crosshead, enclosed type, employing force-feed circulation. The following oil consumption is typical of such engines:

	Grams per Brake Horsepower-hour
Cylinders	0.15
Force-feed circulation system	0.60
Air compressors	0.05

The oil consumption in the force-feed circulation system increases greatly in Diesel ships when going through the tropics, as, because of the higher oil temperature, the oil becomes thinner, which means more oil spray, more oil creeping, and more leakage through joints.

Smaller Diesel engines use more oil per brake horsepower-hour than large engines. The small open-type engines do so because the high r.p.m. throws the oil into the engine room, and with the enclosed trunk-piston type engines it is difficult to avoid excess oil's passing to the piston tops, where it burns and chars.

In open-type land engines the waste oil should be collected and kept in large settling tanks, containing several hundred gallons of oil, so that the oil slowly frees itself from the exceedingly fine carbonaceous matter by the force of gravity alone. Filtering the oil in the ordinary way is useless, as the pores and interstices in any filtering material are like tunnels for the fine carbon particles which therefore cannot be retained. An apparatus to free the waste oil from carbon is described on page 596 (Fig. 224).

In average-size Diesel engines—250 to 500 hp.—the oil consumption if given reasonable attention should not exceed from 2.0 to 3.0 g. per brake horsepower-hour but will rarely be so low as 1.0 g. per brake horsepower-hour.

Oil Pressure.—In enclosed-type trunk-piston Diesel engines, too high oil pressure means excessive oil spray from the bearings, *i.e.*, excessive oil consumption. Considerable saving in oil can often

be made by gradually reducing the oil pressure and watching the oil consumption. When a minimum has been reached, the oil pressure should be increased 2 to 3 lb. as a safety margin. It is often possible to fit effective splash guards *low down* over the crank webs; if correctly made, they reduce excessive oil throw upward into the pistons.

Excessive bearing clearances also cause excessive oil leakage. In modern engines, big end clearances are often down to 0.0005 in. per 1 in. of diameter, which reduces leakage and accordingly oil consumption.

In order to minimize the excess of oil thrown upward into the piston, the big ends should be so shaped that all top edges are well rounded, and bottom edges shaped so that they throw the oil off readily toward the bottom of the crankcase.

REDUCING OIL CONSUMPTION IN ENCLOSED-TYPE DIESEL ENGINES

Gudgeon-pin Leakage.—Figure 208 shows a common type of gudgeon pin with end plates which are bolted togethers, either as shown or without the spring. In either case, such end plates

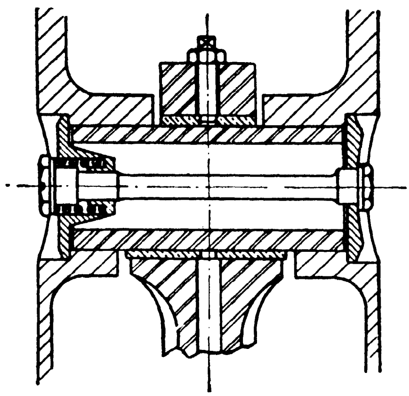


Fig. 208.

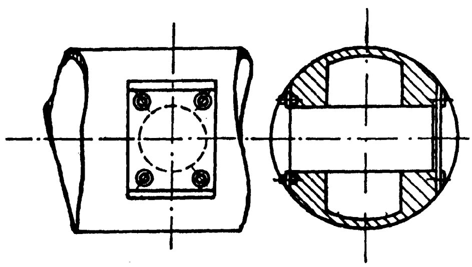


Fig. 209.

Figs. 208–209.—Gudgeon-pin end plating.

have been prone to oil leakage, but this can be overcome by assembling the end plates with a joint of tough sheet packing 0.008 to 0.016 in. thick. This secures an oiltight joint from one overhaul to the next.

Figure 209 shows one of the oldest and best systems of end plating—a steel plate is bedded to the piston face and is attached thereto by four studs and pal nuts.

P. H. Smith suggests that the oil from the gudgeon pin, when running down the inside of the piston, should be prevented from getting on to the liner by shaping the piston skirt at the bottom as shown in Fig. 210; and the roof-oil drainage coming from a sloping crankcase roof may be prevented from getting on to the piston. It would have been better if the crankcase roof sloped the other way.

Breathers.—A *breather* is ordinarily fitted to the crankcase with an open outlet to the atmosphere or a connection to the air inlet.

If the breather outlet is closed temporarily, the crankcase pressure will indicate whether or not there is any considerable "blow past" the pistons, and the pressure can be seen by the rise in the oil-level indicator. A high crankcase pressure is, for obvious reasons, often the cause of high oil consumption, and the leaky pistons should at once be located and put in good condition.

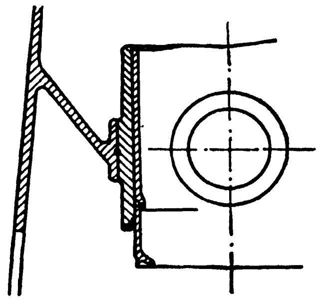


FIG. 210.—Correct piston skirt.

Carbon Deposits.—Carbon deposits may be caused by overfeeding of oil, the use of an unsuitable oil, impurities in the intake air, impurities in the fuel, unsuitable fuel, or incomplete combustion. The first three causes are exactly similar to those mentioned for gas engines, except that with marine Diesel engines the intake air is nearly always pure, but it has been known to carry with it fine seawater spray in suspension into the engine, producing salt deposits and rapid wear.

Impurities in the Fuel.—When the fuel oil contains too much free carbon or ash, the unburned impurities will deposit themselves on the cylinder walls, adhering to the lubricating oil and forming a deposit which will result in heavy wear of cylinder walls and piston rings. Too much water in the fuel will cause irregular fuel charges and interfere with proper combustion, the result being irregular running and even misfiring. Water in the fuel also attacks the fuel valve and its valve seat, causing cutting and fuel leakage.

Sulphur does not appear to affect the lubrication of Diesel engines.

Unsuitable Fuel.—A fuel containing too much asphaltum or too thick to flow readily will not be properly atomized when injected through the fuel valve and does not burn completely during combustion; the unburned portions will accumulate on the piston top, behind and between the piston rings, etc., and form carbonaceous deposits.

Incomplete Combustion.—Correct proportion of injection air to the fuel used is important, in order to obtain complete combustion. Incomplete combustion may be due to the blast pressure's being too high or too low, to the fuel valves, being out of order, or to the use of an unsuitable fuel.

Blast pressures too high for the load, which is particularly likely to occur under light-load conditions or when starting the engine, result in too much air's passing through the fuel valve. Owing to the great fall in pressure, the expansion, resulting in cooling, will cool the fuel spray, so that the fuel is incompletely burned. The unburned portions deposit themselves on the piston tops, and every few strokes the accumulated fuel will spontaneously ignite when the piston rises on the compression stroke, causing preignition and violent knocking.

If the blast pressure is too low, imperfect atomization of the fuel produces deposits because the larger particles of fuel in the spray are not completely burned. With incomplete combustion the exhaust will be black.

Fuel valve out of order will result in incomplete combustion, due to fuel leakage into the cylinder during the exhaust, suction, and compression strokes of the piston. Preignition of the accumulated fuel on the top of the piston will take place at the end of the compression stroke and cause knocking. The constant leakage of injection air through the fuel valve will result in cutting and destruction of the fuel valve and its seat.

DIESEL-ENGINE AIR COMPRESSORS

The *air compressor* which supplies air at high pressure for the fuel injection is in land Diesel engines usually built as part of the engine, being driven from the main crankshaft; but in marine Diesel engines it is sometimes driven by an auxiliary high-speed Diesel engine. The air compressor in two-stroke cycle Diesel engines usually draws its air from the scavenging air supply.

In land Diesel engines below 500 hp. and marine engines below 300 hp. the air compressors are usually of the two-stage type, but many manufacturers fit three-stage air compressors, even for small-sized engines, the tendency being to abandon the two-stage type, in order to obtain lower temperature of the air leaving the compressor. The air compressor in Diesel engines above 500 hp. is practically always three-stage or, for marine service, even four-stage.

PRESSURE DISTRIBUTION IN TWO- AND THREE-STAGE AIR COMPRESSORS

Compressor	Gauge Pressure, Pounds per Square Inch
Two-stage:	
Leaving 1st stage	120 to 150
Leaving 2d stage	900 to 1,000
Three-stage:	
Leaving 1st stage	40 to 60
Leaving 2d stage	120 to 220
Leaving 3d stage	900 to 1,000

Air-compressor Lubrication.—The internal lubrication of the air compressor is considered an important feature in connection with the lubrication of Diesel engines. The oil is here subject to oxidation from the compressed highly heated air.

If an excess amount of oil, or an unsuitable oil, is used, the result of oxidation is the formation of carbon deposits which accumulate principally on the pistons, on the valves, and in the discharge pipes. The valves work at high speed, and even a slight deposit may cause them to work sluggishly or to stick. Under these conditions the air is wiredrawn and recompressed through the delivery valves; the hot air heats the valves; and the temperature may rise easily to, say, 700 to 800°F. or more, which is above the spontaneous-ignition temperature of a mixture of oil vapor and air. The deposit now becomes incandescent, and any accumulated oil will vaporize and explode. Restricted openings in discharge pipes will have the same effect. It is therefore necessary to use only the very best oil, one that has only a slight tendency to carbonize.

The oil must be fed sparingly and uniformly, preferably by means of a mechanically operated lubricator, to the low-pressure piston. The air usually carries sufficient oil from the low-pressure stage to lubricate also the intermediate- and high-pressure

pistons, but in large compressors these pistons may have to be lubricated direct as well.

The intercoolers and oil separators should be drained regularly and frequently enough to prevent the accumulation of oil or water from being carried over to the last-stage air cylinder, where the water might cause the cylinder to burst.

It is perhaps safe to say that over half the troubles experienced with Diesel engines have been in connection with the air compressors; and the general feeling is, quite correctly, that the quality of the oil and the quantity used are chiefly responsible. This whole question therefore demands a thorough analysis.

Dust has been responsible for carbon deposit and is usually easy to discover by chemical analysis of the deposit.

Inefficient cooling of air-compressor cylinders or valve casings has been responsible for a good deal of carbonization trouble; the water spaces have become incrusted with scale or mud from the water, or the water supply has been too scanty, causing high temperatures of the discharge valves, etc.

Fuel oil getting in with the intake air will almost certainly lead to the formation of deposits.

Oil spray in the intake air may be the cause of carbonization when the air compressor take its air supply from the crank chamber, in which the air is charged with finely atomized oil spray.

Too infrequent drainage of intercoolers allows water to be carried over to the smaller dimension higher stage cylinders. The clearance space in the high-pressure compressor cylinder is so small that it is easily filled with water from the preceding intercooler; the water cannot escape through the discharge valve quickly enough, and so the cylinder is fractured.

Intercoolers should be fitted with relief valves big enough to allow all of the air coming from the preceding cylinder to blow off, if the suction valves in the succeeding cylinder are choked; otherwise the intercooler will burst.

Aftercoolers and blast vessels should be drained at intervals. Accumulated oil has been ignited and exploded by high temperature caused by a semichoked discharge valve or pipe on the high-pressure compressor cylinder or by backfire from the engine cylinder, and particularly when oxygen has been used to recharge the blast vessels. This later practice is now condemned. Of

course, such accumulation of oil ought not to occur and will not occur with sufficiently frequent drainage.

Too small number of compression stages means excessive air temperature and increased tendency to carbonize the oil. Under light-load conditions some air compressors throttle the air intake, with the result that the air is really compressed in one stage less and therefore becomes much hotter than under full-load conditions.

Excessive oil consumption is responsible for many cases of heavy carbonization. Where air compressors have low-pressure trunk pistons lubricated by oil from the force-feed circulation system, oil may pass the low-pressure piston in large quantities. The piston rings should be pegged, and splash guards may be fitted to prevent excessive splashing to the cylinder walls. But the amount of oil needed for air-compressor lubrication is small—much smaller than the minimum consumption obtainable under the conditions just described. It is therefore better to design the air compressor so that it can be separately and *economically* lubricated, receiving only the amount of oil actually needed.

There is another reason why the oil consumption should be reduced to the minimum. All the oil that passes through the compressor is subject to the oxidizing effect of the air, and consequently the unsaturated hydrocarbons and perhaps some of the more easily decomposed saturated hydrocarbons as well combine with oxygen, partly decompose, and form petroleum acid, which is said to assist in the thinning of the copper tubes in the coolers, particularly those in the aftercooler. As a confirmation of this explanation one maker found that when he introduced mechanically operated lubricators for the compressors, feeding the oil sparingly to the low-pressure stage only, the life of the cooler tubes was much prolonged, owing to less oil's passing through the compressor and therefore less acid's being formed by oxidation.

It is possible that galvanic action may assist in corroding the pipes. In the afterportion of the coil, where the moisture condenses, the copper is covered with water, which is slightly acid, and, as the coils are joined to steel covers, the three factors needed for galvanic action are here present.

The chief cause of the thinning of the pipes is, probably, the condensed moisture in the compressed air, and it must not be overlooked that air at 80 atmospheric pressure is very dense and

in rushing through the pipes creates great friction, which assists in eroding the soft copper surfaces.

Air-compressor Oil.—In view of the foregoing facts, the question that remains to be answered is, What kind of oil should be used to minimize the danger of explosion?

Formation of carbon deposit is obviously at the root of the problem, because if no carbon were formed, there would, normally, be no excessive temperatures—at any rate not high enough to vaporize or to explode accumulated oil, which, by the way, ought not to be there. Feeding the oil economically by a mechanically operated lubricator reduces oil consumption and therefore means less carbon deposit and less acidity in the water separating out in the coolers and purge pots.

But the character of the oil is of very great importance. Many years ago the author introduced for the first time a compounded oil (containing 3 per cent of animal oil) for Diesel compressors, and the results were that compressors would operate with *perfectly clean valves and pistons* sometimes for periods extending over several months *and notwithstanding rather excessive oil feed.* The explanation appears to be simple: The interior surfaces of the higher stage air cylinders are very wet, in fact streaming with water, which tends to wash away the oil; with mineral oil the water succeeds in washing it away; dry streaks develop; slight wear produces a rusty, spongy deposit, which cakes together with the oil and sticks to the valve seats, discharge pipes, etc. This deposit attracts more oil, continually grows, and, being soaked with oil, may bring about an explosion, as explained on page 432.

A slightly compounded oil will behave differently; it combines with the water and produces a *complete oil film* on the cylinder walls, exactly in the same way as compounded steam-cylinder oils give more efficient lubrication of steam engines employing saturated steam, and therefore can be used very economically.

A suitably compounded air-compressor oil will practically prevent cylinder wear. There will be no rust to form nuclei for the formation of carbon deposits; the valves and discharge pipes will keep clean; and high temperatures are avoided. Such an oil will maintain a better seal on the pistons and valves and will therefore reduce the air leakage past pistons and valves which always produces high temperatures of the compressed air.

The oil should contain about 3 per cent of acidless tallow oil or prime lard oil which must be practically free from acid. Three per cent of lard oil, containing a fair amount of free fatty acid, or even 3 per cent of oleic acid has been used and gives good results as far as freedom from carbonization is concerned, but the fatty acid attacks the copper tubes in the intercoolers, and the after-cooler in particular, forming large amounts of verdigris and causing more rapid destruction of the tubes than when no fatty acid is present.

The air-compressor oil should have a reasonably high flash point—not below 400 or above 450°F. There is no special virtue in using a high-flash-point oil, as that also means a heavy-viscosity oil, which is undesirable. A sluggish oil will attract impurities which may enter with the intake air, and it will thus increase the tendency to form deposits. (See further under "Air Compressors," page 432.)

Scavenging Pump.—The lubrication presents no difficulty, as the air is compressed only 3 to 10 lb. Air-compressor oil should be supplied sparingly and uniformly, preferably by means of a mechanically operated lubricator.

DIESEL-ENGINE OILS

The lubrication requirements of Diesel engines, in normal operation, are very similar to those of vertical gas engines, and the selection of suitable grades of oil follows similar lines, except in the case of marine Diesel engines of the large, open, two-stroke cycle type, which, as mentioned on page 560, require compounded bearing oils for external lubrication. The air compressor, where-ever possible, should also be lubricated by a slightly compounded oil, unless the oil for the compressor is supplied from the Diesel-engine circulation system, in which case the compressor must make the best of the oil used in the main system.

It must, however, not be overlooked that the oils used in the circulation systems of Diesel engines are exposed not only to oxidation from the air but often also to the emulsifying action of water, especially in marine Diesel engines, and that in the latter case this water is especially troublesome, being sea water.

Diesel circulation oils are therefore of the turbine-oil type, and when the same oil is also used for cylinder lubrication, which is frequently the case, noncarbonizing properties are also required.

The service is very trying; high-grade circulation oils are therefore needed, and during service, especially in marine engines, it is good practice to add hot water of condensation to the oil before it enters the centrifugal purifiers; this will help to purify the oil from constituents liable to emulsification and will also continuously eliminate the petroleum acids which invariably are produced during service.

Instead of using compounded oils for internal lubrication of Diesel-engine cylinders, colloidal graphite appears to be very beneficial to improve lubrication and reduce wear of rings and liners. Alan Wolf mentions an instance where tests carried out on a marine Diesel engine of Continental manufacture showed the beneficial effect of adding as little as 0.1 to 0.2 per cent by weight of colloidal graphite to the cylinder oil. On two successive voyages to the East, the average liner wear reached the high figure of 0.015 and 0.012 in., respectively, and every cylinder except one contained broken piston rings. This particular cylinder had been lubricated with the same oil as the others, except that it contained colloidal graphite. In this cylinder, the liner wear had been reduced to 0.008 in., no rings were broken, and the cylinder walls were better than at any time before.

Colloidal graphite must not be added to the circulation oil, as it causes the oil to emulsify with water.

Diesel-engine oils 2, 3, 4, 2c, 3c, and 4c; compressor oil 3*c*; and marine-engine oil 1 are recommended by the author for lubrication of all types of Diesel engines, and a rough guide for selecting the correct grade is here given.

LUBRICATION CHART
For Diesel Engines

Engine	Lubrication system	Horse-power per cylinder	Grade of oil recommended	Viscosity, centi-poises at 50°C.
Four-stroke cycle:				
Open types:				
For cylinders and bearings.	Gravity-feed or mechanical lubricator	Up to 50	Diesel-engine oil 2c or 2	8
For cylinders and bearings.	Gravity-feed or mechanical lubricator	Above 50	Diesel-engine oil 3c or 3	10
Enclosed types:				
For bearings only, crank chamber separated from cylinders by a distance piece.	Force-feed circulation	All sizes	Circulation oil 3 or Diesel engine oil 3	10
For cylinders only......	Mechanical lubricator	Up to 50	Diesel-engine oil 2c or 2	8
		Above 50	Diesel-engine oil 3c or 3	10
For cylinders and bearings.	Force-feed circulation Trunk pistons lubricated by splash from crank chamber	All sizes	Diesel-engine oil 3 or 4	10 or 13
Two-stroke cycle:				
Open types:				
For cylinders only......	Mechanical lubricator	Up to 80	Diesel-engine oil 3c or 3	10
		Above 80	Diesel-engine oil 4c or 4	13
For bearings only......	Gravity-feed or mechanical lubricator; oil not recovered	All sizes	*Marine-engine oil 1	56
Enclosed types:				
For cylinders and bearings.	Force-feed circulation Trunk pistons lubricated by splash from crank chamber	All sizes	Diesel-engine oil 2 or 4	8 or 13

* See page 267.

	Grade of oil recommended	Viscosity in centipoises at 50°C.
For piston cooling of large Diesel engines, when cooling oil is employed:		
a. When the cooling system is separate from the lubrication system	Circulation oil 1	4.5
b. When the cooling system is separate from the lubrication system, but joints leaking badly	Circulation oil 2 or 3	8 or 10
c. When a combined cooling and lubrication system is arranged (the oil must be a pure mineral oil)	Diesel engine oil 2 or 3	8 or 10
For air compressors:		
For the vast majority of compressors, in which a separate oil can be fed to the compressor	Air-compressor oil 3c (see page 436)	10
When the air-compressor cylinders are not separately lubricated, the oil supplied for the Diesel engines has to be used, whether it be straight mineral or compounded, but under no circumstances must marine-engine oil 1 or similar oils be used		
For scavenging pumps:		
Use the same oil as supplied for the air compressor		

NOTE 1: The numbers 2, 3, and 4 refer to the viscosity number of the oils (see page 57); the addition of the letter *c* means that the oil is compounded with fixed oil.

NOTE 2: For circulation oils see page 243.

BRIEF NOTES ON THE LUBRICATION OF MISCELLANEOUS WORKS AND MACHINERY

CHAPTER XXXIII

STEEL AND TINPLATE MILLS

In all tinplate mills (sheet mills), rolling tinplate, and in steel mills, rolling armor plates or very heavy "sections," the roll necks attain a very high temperature—from 400 to 700°F. Ordinary oils will vaporize and leave the necks dry. Such necks are, however, successfully lubricated by so-called hot-neck greases, which should have high melting points to suit the running temperatures of the necks. The spent grease is collected, melted in a grease boiler, mixed with a certain amount of new grease and "mixing" grease, and can then be used over again. When starting the mills cold on Monday mornings, soft cold-neck grease is used until the necks get sufficiently hot to allow the hot-neck grease to be employed. The hot-neck grease is applied hot by a "swab" or, when the temperatures are not too high, in the form of strips, nearly as long as the brasses and of a section suitable for the available room between the top and bottom brasses.

In steel mills rolling not too heavy sections, the roll necks may be kept reasonably cool by a trickle of water running over them continuously. An emulsifying low-melting-point grease, usually a tallow grease ("tallow compound"), should then preferably be used, as it gives excellent lubrication and reduces the wear considerably, as compared with hot-neck greases. If the necks cannot be kept cool enough, the tallow grease melts away too quickly, and hot-neck greases may prove more advantageous, notwithstanding the greater wear and friction.

Tallow greases are applied by placing a lump of the grease against the neck on an inclined plate on both sides of the bearing so that it continuously tends to slide toward the neck. The bottom roll necks frequently have no upper brasses. The tallow grease can then be placed in a sheet-metal housing placed over

the neck and having an opening in the center through which the water trickles on to the neck. Tallow grease may also be applied in the form of strips, as mentioned for hot-neck greases.

When steel mills roll only light sections, the necks are much cooler, and cold-neck grease can be used (No. 2 or 3 consistency), applied either direct to the necks or in canvas bags. The grease slowly melts through the bags, and the lubrication is more uniform and more economical than applying the grease direct. Soft tallow greases may also be applied in bags.

In electrically driven rolling mills the high-speed bearings on the electric motor and the gear bearings are usually lubricated by a force-feed circulation system, using an oil like bearing oil 4[1] or circulation oil 2.[2]

For bearings that are exposed to heat, *e.g.*, bearings of hot metal cars and bearings near soaking pits, a high-melting-point soft or medium graphite grease will give good results.

For bearings exposed to flame, as certain bearings in galvanizing machines, any oil burns the moment it is applied. The best lubricant is finely powdered graphite applied as a powder; if that is not practicable, it should be applied mixed with oil or as colloidal graphite; the graphite will remain in the bearings and prevent undue wear.

For pinions and gearing, cold-neck grease is frequently used, but it is better and more economical to use a suitable pinion grease. Good pinion greases are very adhesive; they should be melted and applied hot by a brush after the teeth have been previously cleaned. The grease solidifies as a thin rubbery coating which will preserve the teeth and assist toward getting silent running. Owing to the great amount of dust and dirt always floating about in steelworks and tinplate works, all bearings that are lubricated by oil should have the oil holes as well protected as possible. Far too little attention is generally paid to this important point.

Bearing oil 5[3] is a good all-round oil to use in steelworks and tinplate works, but there are many purposes for which a black oil of similar or slightly heavier viscosity can be used to advantage, such as table roll bearings, shears, and racks. For mills in

[1] See p. 135.
[2] See p. 243.
[3] See p. 135.

cold climates, good cold test is important, as most of the machinery is more or less exposed to the cold and draft.

COLLIERIES

In modern collieries, steam turbines—high-pressure as well as exhaust steam turbines, are largely used, and where large coke ovens are installed, large gas engines are often employed to make use of the surplus gas.

The fan engines are treated with special care. The fans are the lungs of the mines, and the colliery manager does not change oils or lubricating appliances on the fan engines unless he feels pretty certain that the change will prove beneficial. The lubrication of the various forms of power units, whether operated by steam, gas, or electricity, is treated elsewhere under their respective headings. The lubrication of steam haulage and winding (hoisting) engines is treated on pages 387 to 389 ("Air-operated Engines," page 439). The lubrication of mine cars used in collieries is treated specially on pages 335 to 344.

Of other special machinery employed in collieries may be mentioned coal cutters and screening plants.

Coal Cutters.—There are four principal types of coal cutters, *viz.*, the disk cutter, the bar cutter, the chain cutter, and the percussion drill. All of these machines may be operated either by an electric motor or by a high-speed air-worked engine. The wear and tear of most of the machines is great, because of the rough service under which they usually operate and also the fact that the men operating them do not, as a rule, give the attention to lubrication that is really most necessary in order to prevent too frequent breakdowns.

The machines require two different oils: one for the gear case, which should be a heavy dark steam-cylinder oil which does not leak out easily; and another oil like bearing oil 5[1] for the motor bearings in electrically operated coal cutters and for the air-operated engine in an air-operated machine.

The troublesome bearings to lubricate are the long sleeve surrounding the base of the bar (bar cutters), the vertical disk bearings (disk cutters), and the bearings supporting the chain wheel operating near the coal face (chain cutters).

[1] See p. 135.

When the long sleeve bearing in bar cutters is worn, the oil from the gear case is wasted owing to leakage. As to the other bearings, they are exposed to coal dust and best lubricated by soft grease fed through tubes, so that the bearings are entirely filled with lubricant.

It would seem as if roller bearings or ball bearings could be introduced with advantage for coal cutters in connection with those bearings particularly exposed to coal dust.

The percussion type of drill is operated direct by compressed air at high speed—1,500 to 3,000 blows per minute—requiring a thin oil ("Light Pneumatic Tool Oil," page 442), or it may be operated by a pulsator, as in the Ingersoll electric air rock drill. The pulsator is an electrically driven air compressor with two cylinders and no valves. The pistons force and draw air alternatively to and from the two ends of the drill cylinder; the piston in the drill cylinder moves forward and backward and strikes, say, 300 blows per minute on the drill head. This machine requires a more viscous oil like refrigerator oil 1 (page 460).

In *colliery screening plants* the machinery works in a dusty atmosphere. For this reason ring-oiling bearings have been only a qualified success. The oil wells must be cleaned frequently in order that the oil may render satisfactory service.

Oil siphons are easily choked by dust, but glass-bottle needle oilers have proved very reliable and satisfactory in a good many cases. They are, however, liable to be broken off or smashed.

Lubricating grease is frequently used, either through Stauffer screw-down cups or through compression grease cups, and has given good service under a variety of conditions. The grease fills up the bearing completely and forms a protective fillet at either end, which prevents the entrance of dust to the bearing surface. There is a marked tendency to introduce ball or roller bearings for colliery screening plants and the like, preferably using grease as a lubricant.

MINES AND QUARRIES (EXCLUDING COLLIERIES)

It will be unnecessary to describe the numerous kinds of machines installed in mines and quarries. Most of the power units are described elsewhere, also lubrication of the mine cars. Steam engines often operate with wet steam, requiring low-viscosity

heavily compounded cylinder oils. This applies particularly to small steam units, as steam cranes and steam rock drills.

One feature to keep in mind with air compressors and gas and oil engines is to have the air-intake pipes situated so that only clean air is drawn in or, if the air is full of dust, *e.g.*, in limestone quarries, to provide suitable air filters.

As much of the machinery is exposed, low-cold-test oils must be used in temperate or cold climates, and it is often desirable to use grease in place of oil on bearings exposed to dust or grit.

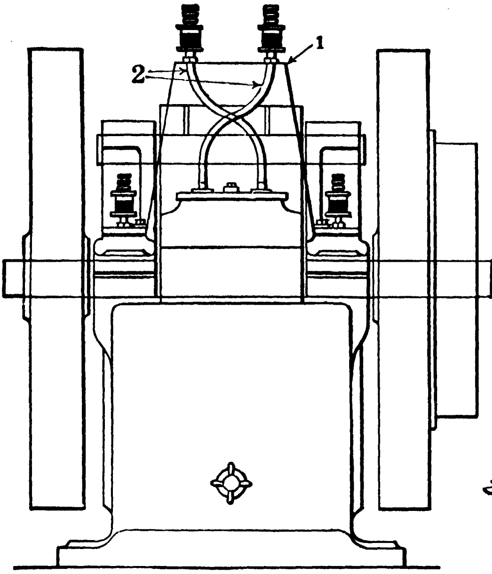


Fig. 211.

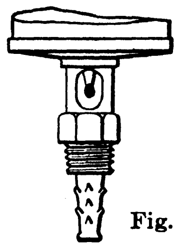


Fig. 212.

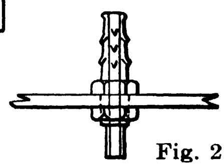


Fig. 213.

FIGS. 211–213.—Stone-crusher lubrication.

An exception is the stone-crusher bearings, which frequently employ grease and are badly lubricated, because grease is not suitable for high-speed work. It is, however, difficult to fix lubricators in the pitman bearing; they usually shake off or go to pieces in a very short time.

Figure 211 shows a method that overcomes the difficulty. A bridge (1) is fixed to the stationary bearings and holds two sight-feed drop oilers in position. These oilers are connected by flexible rubber tubing (2) to the pitman head. Figures 212 and 213 show in detail the tapered fittings to which the rubber tubing is attached. The tubing has an inside diameter of ⅜ in. and an outside diameter of ¾ in.

As there is a great risk of pieces of stone being thrown about by this jaw type of crusher, it is at all times advisable to have light wrought-iron boxlike covers made which can be used to slip over the drop oilers to protect the glasses from breakage and the brasswork from damage. Bearing oils 4 or 5[1] will generally give satisfaction.

In certain types of pneumatic stamping machines an air cylinder is interposed between the stamp and the connecting rod which delivers the blow. The connecting rod takes hold of the air

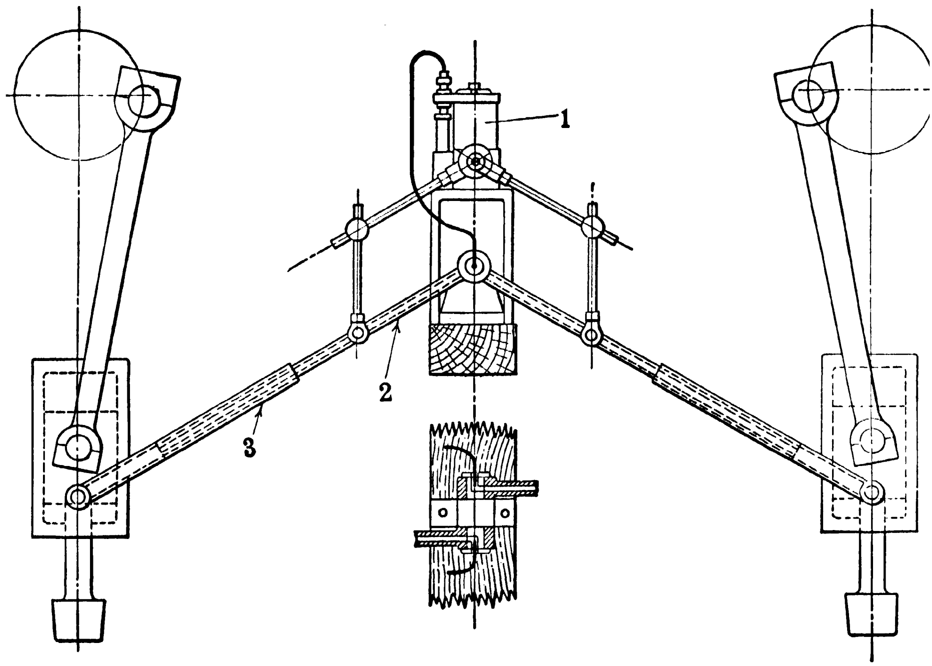


FIG. 214.—Mechanical lubricator for stamping machines.

cylinder and on the downstroke compresses the air above the piston which is connected to and actuates the stamp. When the blow is delivered, the compressed air acts like a buffer and softens the blow. The piston in the air cylinder must be lubricated, and, owing to shocks and vibrations, lubricators fixed on the cylinder generally shake off. One method is to have Stauffer grease cups and to stop the stamps now and again to give the grease cups a turn. Very little lubricant is, of course, required. Grease is, however, a bad lubricant, and output is decreased owing to the stoppages. A viscous oil like compressor oil 2 (page 436) is much

[1] See p. 135.

more efficient, and it can be fed successfully by the method indicated in Fig. 214. The oil is fed from the mechanically operated lubricator (1) into pipe (2) which is telescopically connected to pipe (3). The latter delivers the oil into the air cylinder, being connected to a fitting which allows it to oscillate. As the air cylinder moves up and down, the two telescopic pipes oscillate and actuate the lubricator, and a sparing supply of oil is continuously and automatically delivered to the air cylinder. Figure 214 shows a two-feed lubricator feeding two stamp cylinders.

PAPER MILLS

The exhaust steam from the main steam engines is passed through the drying rolls ("dryers") on the paper machines. It is therefore important to use good-quality filtered cylinder oils, which are easily removed from the exhaust steam, and to use them sparingly. If oil is carried over to the dryers their efficiency is considerably reduced. Many paper mills could probably with advantage mix oildag with their steam-cylinder oil with a view to reducing the consumption. All of the exhaust steam is used for heating purposes, so that even a considerable saving in power in a paper mill by improved lubrication is not important from a power point of view. The reduced quantity of exhaust steam available has to be made up with fresh steam to satisfy the demand for heating and drying purposes.

Improved lubrication is, however, of great importance from a wear-and-tear point of view, which is a considerable item in every paper mill.

The *paper machines* at the "wet end" have a number of rollers, the bearings of which are splashed with water. A very soft clinging grease should be used for the bearings, or a medium-body compounded oil which will "lather" with the water. Next come the dryers, of which there may be a great number, say 20. The paper, which is delivered as a "wet carpet" to the first dryer, passes over or under the other dryers and becomes drier and drier, being finally wound up on to a large reel and taken to the calendars for finishing purposes. The dryers have large bearings placed in cast-iron frames. The bearings become hot because of heat conducted into them from the steam, particularly on that side of the machine where the steam enters through their hollow journals. These large bearings are best lubricated by a

self-oiling arrangement—a collar fixed on the journal dipping into an oil well, and a stationary scraper wiping the oil off the collar and guiding it into the "on" side of the bearing.

In modern paper-making machines, pressure oil-circulating systems to both the drying roll necks and the totally enclosed gears at the back of the machines are frequently employed. Systems such as the Bowser circulating system are often used, including elaborate settling tanks and filtration systems, and the quantity of oil in circulation may amount to as much as 5,000 gal.

The *calenders* are similar to those used in the textile industries and require a very viscous oil of great oiliness, as bearing oil 6[1] or marine-engine oil 1,[2] or even a filtered cylinder stock, heavily compounded like cylinder oil 1 F.H.C. (page 408). High-melting-point fiber grease is occasionally used, but suitable oil is much to be preferred.

Beater bearings are usually very troublesome. The pulp is often thrown up into the bearings and causes heating and scoring. *Suet* is probably as good a lubricant as any for the bearings as now designed. It would seem very desirable to design some form of grease-filled bearing, either plain or roller type, which would stand the heavy strain and which by virtue of being filled with grease would be protected from the entrance of pulp, etc.

There are usually a fair number of small steam-engine units scattered about in paper mills, for driving various machines, pumps, etc. The steam is generally wet and demands heavily compounded cylinder oils. With high-speed enclosed engines, employing either splash oiling or force-feed circulation, great trouble is often experienced owing to an excessive amount of water's getting into the oil. Low-viscosity circulation oils and a system of daily treatment for the oils is therefore essential.

CEMENT WORKS

Some of the most important bearings in cement works are those for ball and tube mills and for the rotary kiln supporting rollers. Most of these bearings receive a great deal of conducted heat from the kiln or from the hot clinker (ball or tube grinding mills). It is good practice to water cool the bottom halves of

[1] See p. 135.
[2] See p. 267.

these bearings, so as to facilitate lubrication. When grinding mills are grinding cold material, the water service is, of course, not required.

The upper "halves" of the bearings are fitted only for the purpose of keeping out grit and dirt and to act as receptacles for the lubricant. Lubrication by means of fiber grease and yarn grease is now customary and quite satisfactory.

Jaw crushers are not often used in cement works; their lubrication is similar to that of stone breakers used in quarries.

Cement works consume a great deal of power; the transmission drives are heavy and require a viscous oil like bearing oil 5.[1] For electric motors, bearing oil 4 should be used, as there are usually heavy belt pulls to deal with.

A fair amount of grease is generally used in cement works (for bearings of elevators, conveyors, etc.) to prevent the dust from entering the bearings.

Pinion grease should be used for the pinions and gears on rotary kilns, etc.

FLOUR MILLS

It has been repeatedly mentioned that in dusty surroundings the use of grease is desirable to keep the dust out of the bearings. In applying this principle to modern flour mills, it must be kept in mind that much of the machinery, such as the grinding machines, operates at high speeds—450 to 600 r.p.m. Grease is not suitable for high speed, except in ball and roller bearings; it wastes a great deal of power, so, where power is costly, grease should not be used. Where there is sufficient water power to drive the mills all the year round, power saving is of no importance, but this is seldom the case, and it should be kept in mind that suitable oils employed in place of grease will save from 8 to 10 per cent in the full mill load. A saving in power of 8 per cent was obtained in one case by replacing very viscous oils by oils of the right character and viscosity.

Bearing oil 4[2] is a good general oil for flour mills. Bearing oil 2 or 3 will be preferable for the grinding machines; being less viscous, they will reduce the power consumption of these machines appreciably, as compared with bearing oil 4.

[1] See p. 135.
[2] See p. 135.

WOODWORKING MACHINERY

For high-speed circular saws and planing machines, bearing oils 2 or 3,[1] preferably slightly compounded, are usually satisfactory.

Heavy band saws require bearing oil 4 or even marine-engine oil 1[2] when the band pull is great. Marine-engine oil 1 may also be used for chains and chain wheels, as it clings tenaciously to the surfaces. For very rough slow-speed bearings and guides of log machinery, black oil is often used and is quite good enough.

Owing to the high speeds at which most machines operate in the finer class of woodworking machines, the selection of the correct grade of oil with a reasonably low viscosity will often accomplish excellent results from a power-saving point of view, and the use of grease should be confined to slow-speed bearings, unless they are ball or roller bearings.

PRINTING MACHINERY

The important machines are type machines and rotary presses.

Type Machines.—For linotype machines, bearing oil 4[3] will prove satisfactory. For monotype machines, a highly filtered steam-cylinder oil, straight mineral or slightly compounded with acidless tallow oil, will prove efficient. Unsuitable oil carbonizes exposed to the great heat, and the type sticks together.

Rotary Presses.—These machines operate at high speed and are driven by variable-speed electric motors. The power consumption is an important factor, and, generally speaking, most presses employ oils far too viscous to give the best results.

Savings in power ranging from 10 to 25 per cent have been accomplished by the introduction of bearing oil 2 or 3.[4] The oils are preferably compounded with a nongumming oil like good lard oil, as most bearings are hand oiled, but straight mineral oils will also render good service. For the electric motors, bearing oil 2 will generally be found to be the correct grade.

HYDRAULIC PLANTS

Apart from pumping engines in waterworks, hydraulic pumps are extensively used in steelworks, collieries, many engineering

[1] See p. 135.
[2] See p. 267.
[3] See p. 135.
[4] See p. 135.

works, and for hydraulic elevators, etc. All hydraulic pumps operate at slow speed. Large pumping engines are usually operated by steam; small hydraulic plants, either by steam or by electric motors. Gas and Diesel engines are very occasionally used; they have the disadvantage that they run at high speeds and so necessitate a great reduction in speed, by either two or three sets of reducing gears or by worm reduction gears. Steam engines are easily operated at low speeds and drive the pumps direct.

Most hydraulic pumps operate at very low speed and pump water against great pressure. These conditions call for viscous oils with great oiliness for lubrication of cranks and main bearings such as bearing oils 5 and 6[1] and[2] marine-engine oils 1 and 2. Occasionally, white greases or others rich in animal oil or fat are used and give satisfaction for very slow-speed work. Mineral cup greases or solidified oils are seldom suitable, being deficient in oiliness.

The pump plungers are often difficult to lubricate, particularly when the stuffing boxes are packed with soft fibrous packing like hemp or flax. Such packing is usually soaked with tallow or graphite or steam-cylinder oil and graphite. The addition of graphite is very desirable; it helps to produce a good surface and prevent scoring. Pressure water, when it leaks through the stuffing box, has an intense cutting action on the plunger surface, and it is the rule rather than the exception to find hydraulic plungers scored. If the attendant, to stop a leak, screws the packing up hard, intense friction is set up in the gland, lubrication may fail, and the trouble is aggravated. The plungers are often lubricated externally by cylinder oil or grease. A compounded low-viscosity cylinder oil or a mixture of lard oil and heavy engine oil is quite suitable, but most greases increase the gland friction enormously; they do not distribute themselves properly and cannot withstand the great pressure between the plunger and the packing.

U- or L-shaped leather packing is coming much into use (on lines somewhat similar to the packing shown in Fig. 163, page 449) and is easier to lubricate than fibrous packing.

[1] See p. 135.
[2] See p. 267.

In plants where the water, after use in the various hydraulically operated engines, returns to a main tank and is circulated afresh, the ideal method of lubricating the plungers and valves in all pumps and engines is to make the water carry the lubricant. This is best done by adding 10 per cent of a soluble oil or compound, which forms an oily emulsion with the water. A rich cutting oil can also be made to emulsify when the requisite amount of borax or soda is added to the water (see page 620). In plants where the water is used over and over again, the introduction of soluble lubricants into the water, where this system has not previously been used, gives results that are never forgotten.

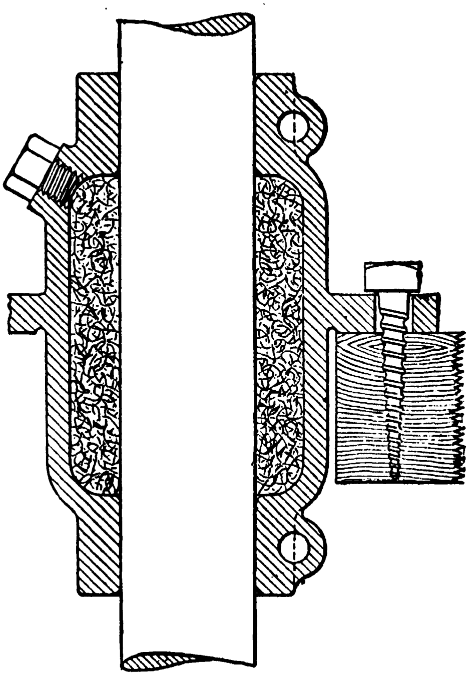


FIG. 215.—Elevator rod lubricator.

The very long plungers in hydraulic elevators are also efficiently lubricated in this manner; but when the water is run to waste and therefore cannot be used as a lubricant, the plunger must be oiled; an oiler as shown in Fig. 215 may be used. The oiler is made in two halves clamped together around the plunger. The oiling chamber is filled with oil-soaked felt or waste, and oil can be applied through a filling hole closed by a screw plug or by a self-closing ball valve.

Some hydraulic plants, *e.g.*, hydraulic elevators, employ wire cables running over a number of sheaves. The sheaves are lubricated by cup grease (of No. 2 or 3 consistency), as it is not possible to get near the bearings. Most sheaves have a number of grease cups with feeding tubes going to the bearings, so that in any position there is always one grease cup close at hand, which can be given a turn. The cables should always be well oiled to preserve the strands from corrosion and wear. Grease does not penetrate the cables and should not be used.

GEARS

Large, heavy-type toothed gearing as employed in steelworks, many hydraulic pumping stations, cement works, etc., is best lubricated by an occasional application, say every 4 to 8 weeks, of a suitable semisolid lubricant. The gears must be cleaned before the first application, and the grease should be applied hot and sparingly by means of a brush, so as to form a thin resilient coating.

The lubricants most satisfactory for heavy-gear lubrication are good-quality pinion grease and exceedingly viscous, semisolid petroleum residues, similar to certain wire-rope lubricants. The admixture of fine graphite is often advantageous, particularly with worn gears. Low-viscosity products are unsuitable; they do not produce a film thick enough to reduce noise and prevent wear.

High-speed toothed gearing as employed in gearboxes of automobiles, motor trucks, elevators, certain machine tools, etc., is usually enclosed in an oiltight casing and is best lubricated by oils of suitable viscosity.

As most semisolid lubricants containing soap are inclined to cake and cause trouble, a mixture of such lubricants and gear oil should be resorted to only when there is a very great leakage with gear oil.

Worm gearing and worm-wheel gearing require oils of great oiliness, owing to the great pressure per square inch between the teeth. The most successful lubricant for extreme conditions of pressure and temperature is castor oil. It possesses great oiliness and an excellent cold test. For elevators, it is very serviceable, as the worm gears are often exposed to the cold. A mineral oil to stand up to the pressure must be of a steam-cylinder-oil nature and compounded with, say, 6 to 10 per cent of tallow or rape, but such oils have poor cold tests as compared with pure castor. As a result, they may be in a congealed state when the gear starts up in the morning; they do not therefore distribute themselves over the worm and wheel, and before they become liquefied by the frictional heat, the gears may have seized.

Where too low temperatures are not encountered, compounded steam-cylinder oils are often preferable, as they do not gum like

castor oil. Dark cylinder oils are usually better than filtered cylinder oils as regards cold test. The admixture of a small percentage of fixed oil is almost as effective as a higher percentage; it greatly improves the oiliness of the mineral base and assists in reducing friction and preserving the teeth from wear.

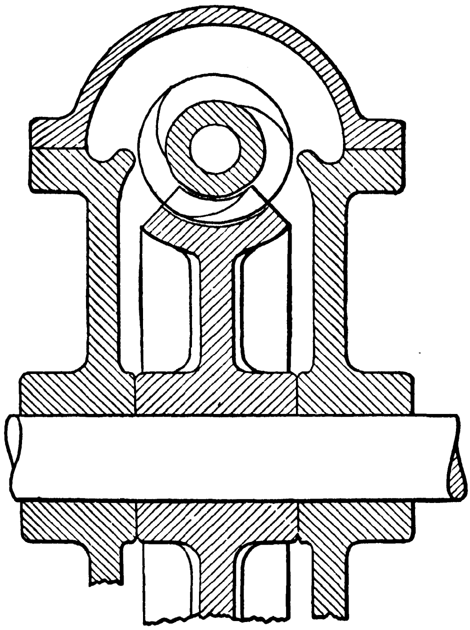


FIG. 216.—Worm-gear lubrication.

Admixture of colloidal graphite is often advantageous.

Semisolid lubricants containing soap are not so satisfactory as good-quality oils, and high-melting-point greases should always be avoided, as the worm or wheel simply pushes the grease to one side, and it never gets a chance to distribute itself, unless the temperature rises high enough to melt it.

As to methods of application, there is generally an oil well into which either the wheel or the worm dips, according to their position relative to one another. Figure 216 shows how it is possible to make use of the oil thrown away from the worm, by collecting it in side troughs whence it may be guided to the thrust bearing and other bearings, finally returning to the oil well.

CHAINS

When chains are entirely enclosed in an oiltight casing, they are best lubricated by a bath of oil, like bearing oils 4 and 5[1] or oils of even higher viscosity, if the casing is not perfectly tight.

Where chains operate exposed to dust and dirt, as transmission chains in automobiles and motor trucks, it is best to remove them at intervals, clean them with kerosene or cleaning oil, and afterward soak them in a bath of melted good-quality tallow and finely powdered graphite. The tallow may be replaced by a No. 2 consistency cup grease containing a heavy-viscosity mineral oil.

[1] See p. 135.

The solidified coating stays a long time and prevents to a large extent the entrance of dirt and moisture.

Lubricating exposed chains by dropping oil on to them before or during operation is wasteful and seldom effective. Viscous oil is almost useless. When it is not possible to remove the chains for soaking in lubricant, *e.g.*, heavy chains in steam shovels and dredging machinery, the lubricant should be applied hot by means of a brush, as with heavy gears.

ROPES

Wire Ropes.—Most wire ropes, as used in collieries and other mines, have a hemp core to make them flexible. When ropes have to withstand severe heat or great crushing stresses hemp cores are unsuitable, and steel centers are substituted.

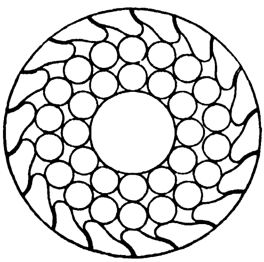


FIG. 217.

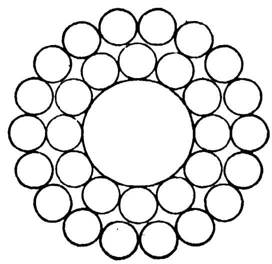


FIG. 218.

There are two main types of wire rope: those with lock-coil construction (absolutely smooth surface) and those with ordinary coil construction, as shown in Figs. 217 and 218, respectively.

Wire ropes deteriorate with use, and their life is greatly influenced by lubrication. If the strands of the rope are not thoroughly lubricated or protected, moisture will penetrate into the rope and cause rust and corrosion. The corrosion may be accelerated by galvanic action, if acid is present in the water or in the lubricant. "Stockholm tar" at one time was a cherished rope lubricant, used either alone or mixed with tallow, rosin, graphite, etc. Such mixtures are unsuitable, as Stockholm tar and rosin contain acids. Tallow also gets rancid and assists in causing corrosion. It is very difficult to prevent corrosion in wire ropes, in which the hemp core has become "chewed up," owing to the rope's having been subjected to excessive strains.

Lubrication of wire ropes is important, not only to prevent corrosion but also to minimize the friction between adjacent strands

rubbing against one another when the rope passes over pulleys or drums; a well-lubricated rope, in turn, lubricates the sheaves, pulleys, etc., over which it passes.

Too much attention cannot be given to saturating the rope with lubricant during manufacture and so giving it a good start. The hemp core should first of all be thoroughly dried and then saturated with melted lubricant which afterward solidifies. Before each successive layer of strands is laid on, the rope must be coated with melted rope lubricant, so that the rope when leaving the manufacturer's works is filled and saturated with lubricants that possess great staying and moisture-resisting properties. It is very important that the lubricants be free from acid, alkali, and moisture and free from animal or vegetable oils or fats, tar, rosin, filling matter, etc. Otherwise, corrosion sets in, and, if the different layers of strands are not identical in quality of steel, galvanic action takes place in the presence of moisture, acid, or alkali and accelerates corrosion of the strands.

The best lubricants for saturating wire ropes, and also for their lubrication, are very viscous dark steam-cylinder oils or other viscous petroleum residues, used either alone or mixed with petroleum jelly to solidify them. Such lubricants can be obtained pure and free from acid, alkali, and moisture, and they possess good lubricating properties. They are applied hot. The rope is passed through the bath of liquid lubricant, surplus lubricant being squeezed off, as the rope leaves the bath. When in use, the strands have a tendency to force the lubricant to the surface, so that occasional application of rope lubricant is required, say, every fortnight under dry conditions and more frequently under wet conditions or when the ropes work in inclined mine shafts or horizontally, as the lubricant then gets rubbed off sooner.

As to methods of applying the lubricant, hand greasing is still largely used. The lubricant is applied by a brush and usually hot, so as to give a thin coating. If the rope gets dirty, it should be cleaned before applying the lubricant. A simple method is to run the rope through a mop which removes loose dirt and moisture.

Hand application is now often replaced by rope oilers, *e.g.*, the one shown in Fig. 219. It consists of a cast casing (1) made in two halves, which are hinged together and clasped round the

rope. The cup-shaped portion of the casting (2) is filled with the lubricant or with sponge cloth, thoroughly soaked with lubricant. In action, the rope passes through the oiler. The guide pulleys (3) keep the rope central and serve to distribute the lubricant over the rope surface. The oiler can be used on horizontal ropes, but the cup (2) must then be enclosed.

Some oilers have a metal washer, an old rubber pump valve, or a piece of ordinary burlap fitted round the rope before it leaves the oiler, so as to wipe off surplus lubricant. Metal washers are undesirable, as with loose strands in the rope (due to wear) the

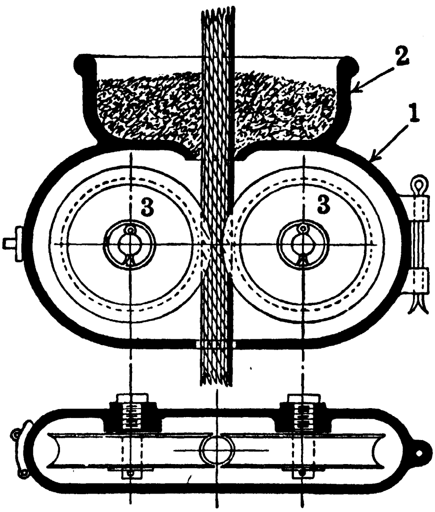


FIG. 219.

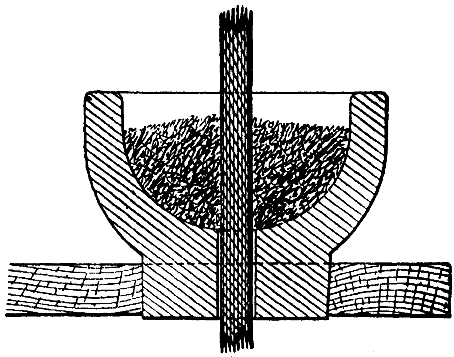


FIG. 220.

FIGS. 219–220.—Rope oilers.

washers will strip the rope. Rubber washers wear out quickly. One pint of lubricant will suffice for coating 100 yd. of 2- to 2½-in. rope.

Quite a simple oiler is shown in Fig. 220. It consists of a wooden cup made in two halves; the cup is pushed into a hole in a plank which may be fixed across the king posts of the winding head. A sponge cloth is placed in the cup soaked with lubricant. A wooden cup will last a long time if made of good hard wood and will not be torn by a stranded rope.

The author is not in favor of rope oilers that employ saturated steam or compressed air for atomizing the rope lubricant and spraying it on to the rope. Steam introduces moisture into the lubricant and the rope, and it is difficult both with steam and with compressed air to avoid waste of lubricant.

The lubrication of *transporter ropes* of aerial ropeways is sometimes done by a man who is carried along the rope and paints it, but a much simpler method, which saves labor and time, is shown in Fig. 221. One of the rope pulleys running on the transporter rope has both sides covered in by steel plates, secured by bolts as shown. The annular space forms an oil reservoir, provided with a filling plug through which oil is introduced. The oil must be just fluid enough at atmospheric temperature to leak slowly through the small hole or holes provided in the rim and thus reach and lubricate the transporter rope. Adjustment is made by plugging some of the holes until a suitable feed is attained.

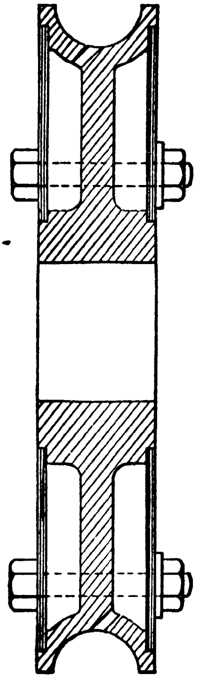


FIG. 221.—Lubricating transporter ropes.

A satisfactory wire-rope lubricant must fulfill the same requirements as the lubricants used for saturating the rope. It must remain soft and pliable under the atmospheric conditions and must not be attacked by the mine waters with which it comes in contact and which often contain acid or chemicals. It must not be thrown off or rubbed off too easily, yet it must be sufficiently fluid to penetrate through the strands to the core and so keep the rope well lubricated internally. It must not harden or peel when exposed to cold and dirt.

It will be clear from these remarks that very viscous or semisolid lubricants of a pure hydrocarbon character will fulfill these conditions. Thin oils, black car oils, or waste oil are often used, but they are almost useless, as they lack viscosity and lubricating properties.

Rope greases containing rosin soap or soap of any kind or filling matter should not be used. They do not work their way into the rope; are inclined to cake and peel; and if they contain acid they cause corrosion.

Wire ropes should be examined daily by a competent person, when the condition as regards wear, lubrication, etc., can be observed.

Driving Ropes.—In the foregoing, reference has been made only to wire ropes. The driving ropes employed for power

transmission are made entirely of fibrous material, such as cotton, manila hemp, etc., and seldom require lubrication, but in manufacture they should be more or less soaked with a preservative and lubricant. A serviceable compound is made from saponified tallow, paraffin wax, and graphite. The compound will solidify and remain in the rope during its entire life.

CHAPTER XXXIV

OIL RECOVERY AND PURIFICATION

The waste oil from bearings of steam engines, gas engines, large shaft bearings, etc., if collected, may often mean a considerable amount, particularly if reasonable care has been taken to stop leakages by fitting efficient splash guards and save-alls.

Such waste oil, if pure mineral or only slight compounded, can easily be made as good as new and used over again. If the oil is heavily compounded and has been mixed with water, only the nonemulsified portion can be recovered. This is best done by simple heating in a settling chamber, when the nonemulsified oil will accumulate at the top.

The greatest economy is generally obtained by placing oil purifiers—settling tanks or filters—in the respective engine rooms or departments, and the attendant should be made responsible for the oil consumption.

In the following will be described some of the interesting aspects of oil purification; also, a few notes will be given regarding clarification of oil charged with carbonized matter and of cylinder oil from exhaust steam and the recovery of oil from cleaning materials.

Oil Purification.—Purification of oil, whether it be waste oil from engines or machinery or oil in continuous circulation, as in steam turbines, consists of three processes, *viz.*, Screening, "Precipitation," and Filtration, provision for all of which is usually embodied in oil purifiers, or, as they are generally termed, oil filters.

Screening.—The prime object of the screen is to retain the coarser impurities and relieve the filter section of as much work as possible.

Precipitation.—In the precipitating chamber, fine impurities of higher specific gravity than the oil, such as fine metallic wearings or water, are precipitated. The action is sometimes accelerated by heating the oil, as the lower its viscosity the more

quickly the impurities will separate out. Heating also tends to break emulsion films. Efficient precipitation is very desirable to enable the filter section to operate for long periods without cleaning. Separated water should be automatically ejected from the system by an automatic overflow.

Filtration.—The object of filtration is to remove the very finest floating impurities in the oil which cannot be retained by the screen or precipitated in the precipitating chamber.

Filtration must not be done by the wet method. Passing dirty oil through water does not remove impurities. The oil rises through the water in drops; the impurities are inside the drops and cannot possibly be absorbed by the water, however hot the latter may be. Dry filtration is the only satisfactory method.

In some small oil filters the oil is purified by siphoning from the dirty oil compartment through woolen siphons into the clean oil compartment. Only clean and fairly dry oil will pass through the siphons.

Most small filters employ cotton waste, wood wool, or other loose material as a filtering medium, but in larger filters, filter cloth is now universally adopted.

The disadvantage of loose material is that when this is loosely packed, the oil passes through channels and passages without being filtered. When the filter material is tightly packed. the capacity is very small, say not more than 1 or 2 gal. per day. Even for small filters, filter cloth in the form of a simple bag is preferable to loose filter material.

In Europe, small filters are seldom made with settling chambers. When the waste oil is very dirty, it is first treated in a steam-heated settling tank, and the oil, freed from water and coarse impurities, is then afterward treated in the filter.

Filter cloth should preferably be so arranged that the impurities retained have a tendency to drop away from the surface. With horizontal filter surfaces the oil should therefore pass upward. Vertical filter surfaces are more satisfactory than horizontal surfaces with oil passing downward through the cloth, as with the latter the dirt tends to clog the filter cloth more than with vertical surfaces.

It is desirable to have the two sides of the filtering surface exposed to the same difference in oil pressure at all points. If

the oil at the bottom of a filter cloth is forced through at greater pressure than at the top, the cloth at the top will pass less oil than the bottom portion, and, on the other hand, coarse particles may be forced through at the bottom, unless the cloth is tightly woven.

When the oil contains very fine impurities, a large area of filter cloth is required, and a slow flow of oil through the filters.

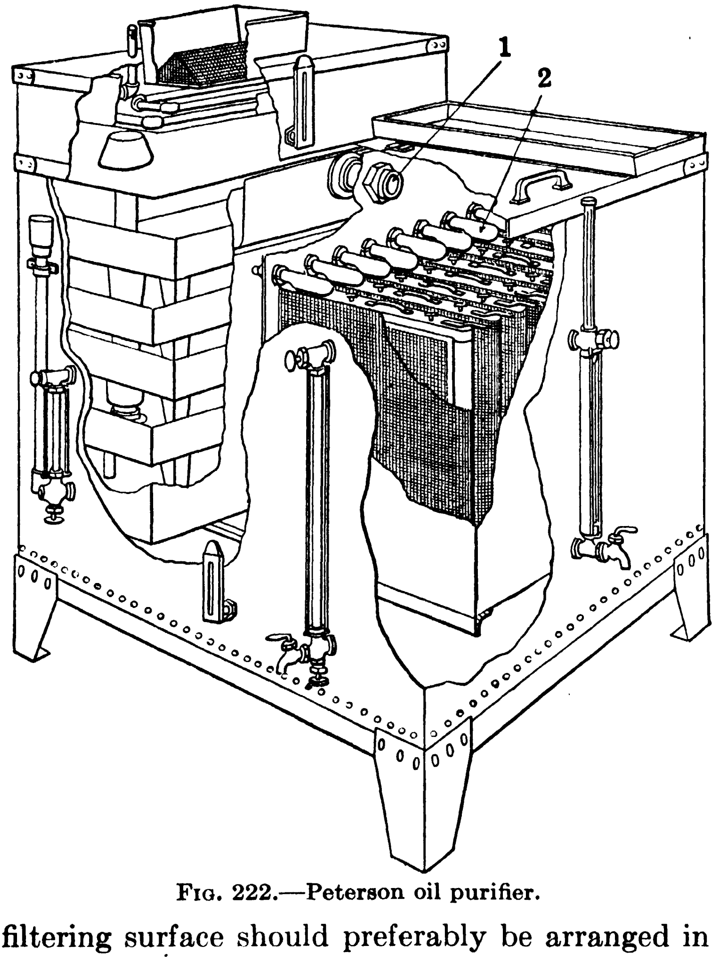


FIG. 222.—Peterson oil purifier.

The filtering surface should preferably be arranged in several units, so that any unit can be removed for cleaning or be quickly replaced by a clean filter unit, without interfering with the operation of the other units. Figure 222 shows a No. 5 Peterson oil filter, made by the Richardson-Phoenix Company, Milwaukee. The precipitation chamber is illustrated in Fig. 223 and shows how water from the various trays passes to the bottom without any danger of being picked up again by the oil. The head (1) in the

automatic water overflow is adjustable vertically to suit the gravity of the oil. The oil flows from the precipitation chamber (Fig. 222) through connection (1) into the filter chamber, passing through the cloth in the filter units to the interior of each unit and through the outlets (2) into the clean oil compartment formed between and below the precipitation chamber and the filter section. When one of the filter units is removed, its respective passage (2) is automatically closed by a spring-actuated valve, which is pushed open when the unit is again placed in position. The

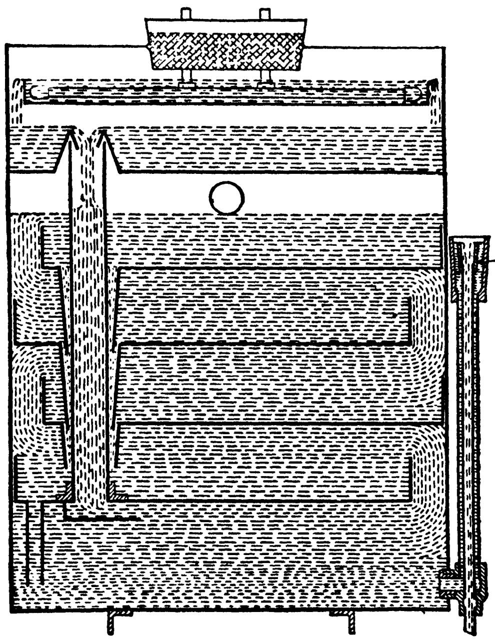


FIG. 223.—Precipitation chamber.

pressure that drives the oil through the filter cloth is the same at all points, being equal to the difference in height between the oil level in the filter chamber and that in the outlets (2).

When desired, a cooling coil may be fitted in the clean oil compartment. Such filters are used as separate units to deal with batches of waste oil and also in connection with gravity circulation-oiling systems for steam engines, the whole of the return oil passing through the filter.

In steam-turbine plants, the flow of oil is too great to be taken care of by the filter, but it is quite sufficient to by-pass, say, 5 per cent of the circulating oil through the filter, to maintain the oil in good condition.

Purification of Oil Charged with Carbonized Matter.—The waste oil from internal-combustion engines is always dark because of contamination with fine carbonized matter, which cannot be separated out by filtration. Gravity separation in large tanks will in time allow the oil to free itself, but it means a large volume of waste oil, and the process is very slow.

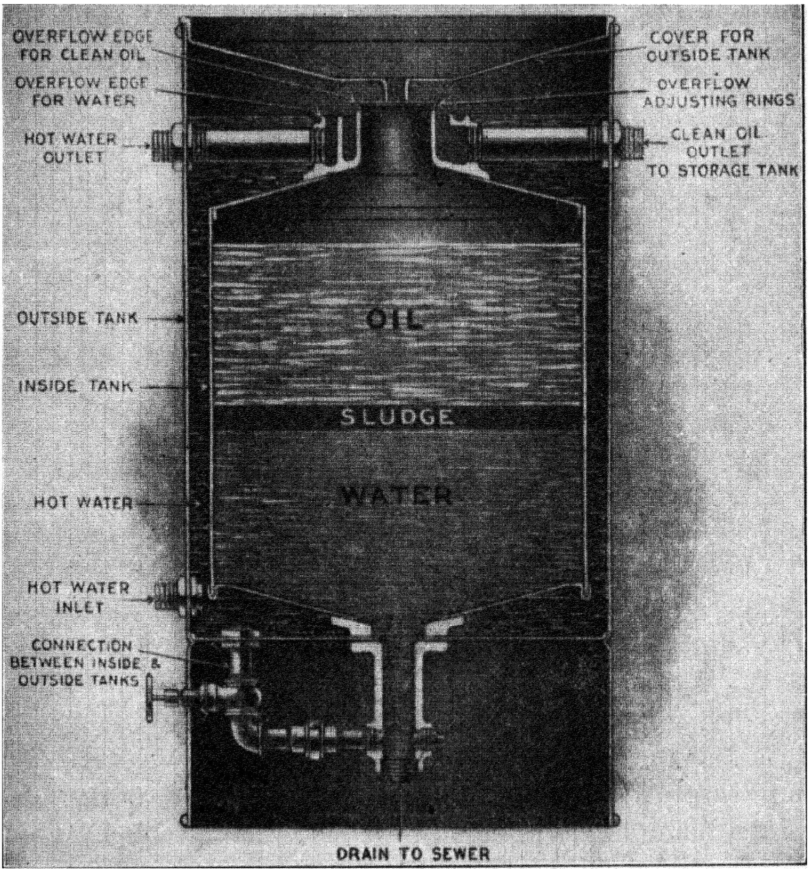


FIG. 224.

Several attempts have been made to coagulate the carbon particles, so that they will become large enough to settle out quickly. A process, which is reported to be working successfully in the United States, has been adopted by the De La Vergne Machine Company. This consists in a brief but violent agitation of the dirty oil with a solution of hot water containing the coagulant, which is a phosphate of the alkali metals, *e.g.*, trisodium phosphate. The action is purely mechanical. Within a few hours after agitation all carbonaceous matter is precipitated

in the form of a layer of sludge between the oil and the water. It is claimed that the oil is not affected by the coagulant. Figure 224 illustrates one form of this apparatus.

Synopsis of Operation:

1. Fill the inside tank with equal parts of water and oil.
2. Heat the contents, and keep it hot during the entire process by circulating hot water through the outside tank.

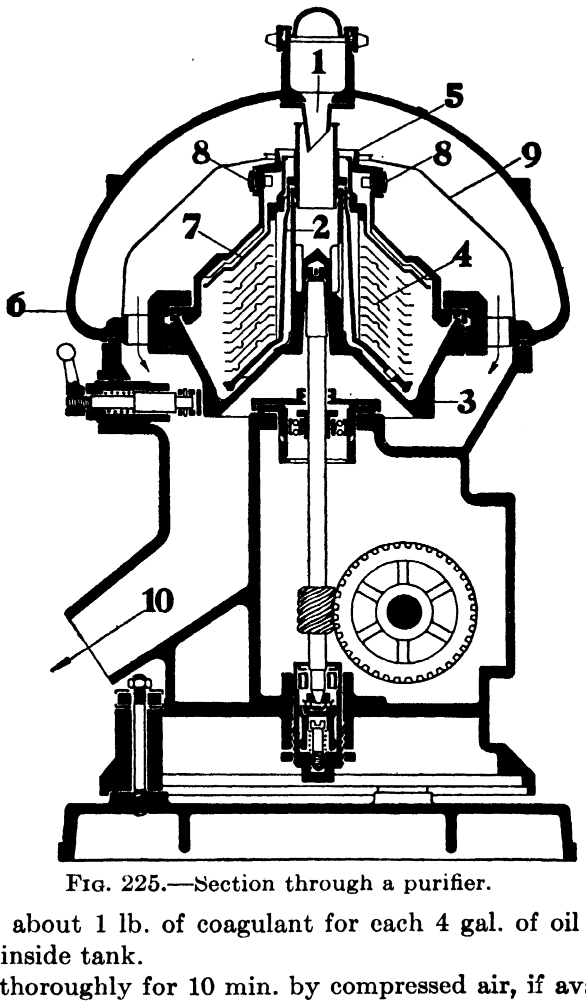


FIG. 225.—Section through a purifier.

3. Dissolve about 1 lb. of coagulant for each 4 gal. of oil in hot water, and put it in inside tank.
4. Agitate thoroughly for 10 min. by compressed air, if available, otherwise by mechanical stirring.
5. Let the contents settle for about 10 hr.
6. Draw off the clean oil by opening the communicating pipe between the two tanks. It will overflow over the inside edge of the top collar at a gradually decreasing rate. Adjust the height of edge by adding rings until the overflow stops automatically shortly before all clean oil is drawn off.
7. Drain the tank, and it will be ready for the next charge.

Centrifugal Purification.—The most modern and only really efficient method of purifying oil is, however, by centrifugal purification, the centrifugal force having a precipitating action several thousands times more powerful than that of gravity alone. The result is perfectly sharp separation between the oil and the impurities.

Figure 225 shows a section through such a purifier, and Fig. 226 an external view of the purifier electrically operated.

Centrifugal purification is mentioned under "Steam Turbines" (page 223) and "Diesel Engines" (page 558).

Centrifugal purifiers are used for a great many other purposes, such as the purification of automobile-crankcase oil, gas- and oil-engine oil, waste lubricating oil from large factories, cutting oil from automatic lathes, and quenching and hardening oils.

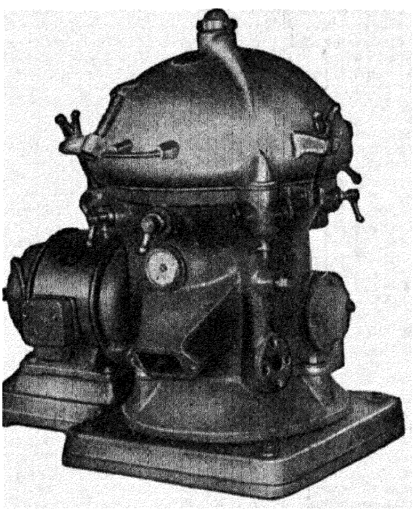


Fig. 226.

The Action of the Centrifugal Purifier.—The impure oil flows through the oil funnel (1) and the center tube (2) to the bottom of the bowl (3), which contains a number of conical purifying disks (4) and rotates with a speed of 6,000 to 9,000 r.p.m. The oil is subjected to the powerful purifying action of the centrifugal force, rises through the many spaces between the disks, and is thrown off at the oil outlet (5), leaving the clean oil cover (6) through the discharge pipe (not shown). Heavy-gravity dirt remains in the large dirt space surrounding the disks.

If the oil contains an appreciable amount of water, this water will pass round the edge of the water-sealing plate (7) and be continuously discharged through the water outlets (8), leaving the water cover (9) through the discharge pipe (10).

In order to discharge the water automatically in this manner, whether the oil contains a larger or smaller quantity, sufficient water must be poured into the bowl before starting normal operation, in order to establish a water seal, *i.e.*, a cylindrical wall of water, which covers the inner surface of the bowl and prevents

any oil from escaping around the edge of the water-sealing plate.

When dehydrating transformer oil or other oils containing only a small amount of water, the water-outlet screw (10) is replaced by a solid plug. All water separated out from the oil will then remain in the bowl.

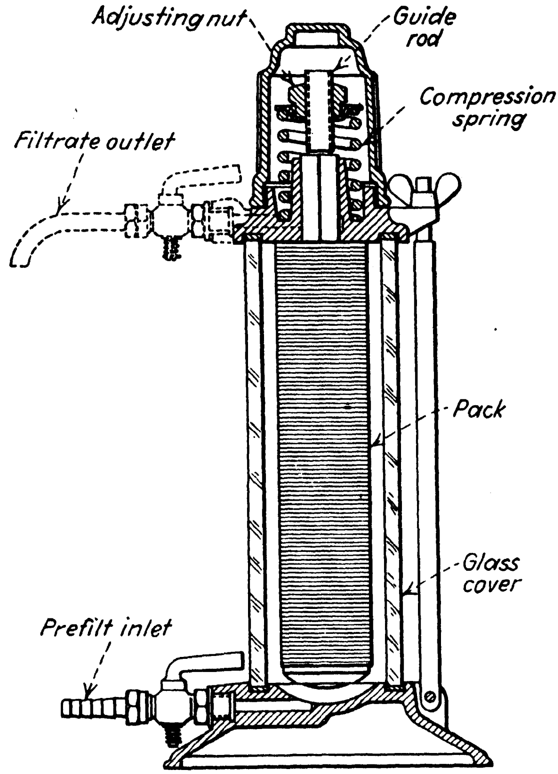


FIG. 227.—Laboratory streamline filter.

Cylinder Oil from Exhaust Steam.—As mentioned elsewhere, cylinder oil in exhaust steam is usually present in a more or less emulsified condition. The oil skimmed off the hot well or recovered from the exhaust-steam oil separator contains water, which is difficult to remove.

A fair amount of success has been obtained by passing the wet oil through a separator, similar to a cream separator. The oil corresponds to the cream, the water to the milk, and, by proper adjustment, practically all the oil can be recovered in a reasonably dry condition.

Recovering Oil from Cleaning Material.—The cotton waste or rags, sponge cloths, mutton cloths, etc., used for wiping or cleaning machinery absorbs a great deal of oil, which can be recovered, as well as the cleaning material, by treatment in machines exactly similar to those used for the recovery of cutting oils from swarf, mentioned on page 612. The waste, cloths, etc., may be washed in a washing machine and dried on wire-

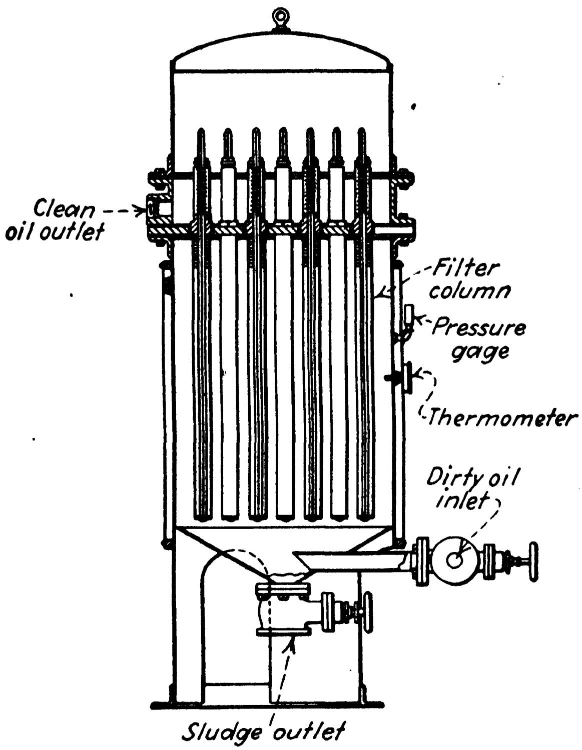


FIG. 228.—Streamline filter.

netting trays in a drying cabinet, being then as good as new. The recovered oil is dirty and must be treated in a steam-heated settling tank and afterward filtered, before use. Unless it is completely purified, it must be used only on rough machinery.

Streamline Filters.—These filters were invented by H. S. Hele-Shaw and are designed to remove the finest possible mechanical impurities. The principle of the filter will appear from Fig. 227, which shows a laboratory unit. A pack of thin paper disks are forced together by a pressure determined by the compression spring. The dirty oil enters below, is forced by a

rather great pressure through the paper disks, and leaves by the outlet shown.

The impurities collect on the outside of the pack and do not enter the paper disks.

Figure 228 shows the section of a large filter in which a number of units are employed. When it is desired to clean the filter, compressed air supplied from a compressed-air bottle is admitted inside each unit. The air is forced through the paper packs to the outside and loosens the cakes of impurities, covering them so that they crumble and drop to the bottom of the container whence they are easily removed.

When filtering transformer oils, the oil is usually heated to make it flow more easily through the packs. To the filter are attached a wet vacuum pump to draw away the oil and a dry vacuum pump to remove air and moisture.

By these filters, insulating oils may be perfectly freed from mechanical impurities and moisture and regain their maximum dielectric strength.

CHAPTER XXXV

OIL STORAGE AND DISTRIBUTION

In most plants, whether large or small, great economies may be secured by paying proper attention to the system of oil storage and distribution. In small plants the oil is usually stored in the barrels as received. It is important, as mentioned page 71, that they be stored under cover in a dry place. The barrels are placed on racks along one side of the room and fitted with barrel taps for drawing off the oil. It pays to have good barrel taps, particularly for thick oils like cylinder oil. The taps should have a large bore and opening (say 1 to 1¼ in.) and a clean "cut off," so that the minimum of dripping takes place after the oilcans or oil jacks are filled. The drippings should be caught by drip pans and can be used for less important machinery after accumulated dirt and impurities are separated out.

The practice of storing the oil in the barrels is not at all satisfactory. A great deal of oil is often wasted, and if the oil from the drip pans is not thoroughly cleaned, it may cause a great deal of trouble. It is better practice to keep the oil in cabinets fitted with a lid, which can be padlocked, so that no unauthorized person can get access to the oil. The cabinets are filled direct from the oil barrels. The oil in the cabinets is kept clean. They have a hand pump for delivering the oil into the oilcans, and surplus oil drains back through a sieve into the main reservoir, so that no oil is wasted.

Such cabinets may also be arranged with self-measuring oil pumps, as supplied by S. F. Bowser & Company. The pump can be adjusted to give a half-pint, pint, or quart for one full stroke of the pump. An advantage of oil cabinets is that they are practically fireproof. They can be placed not only in the oil house, but also in engine rooms or anywhere in the mill or factory where it is desired to have an oil distributing unit. Cabinets for departmental use, when empty, may be transported to the oil house,

refilled, and again delivered to their respective departments, which are then debited with the amount of oil filled into the cabinets.

Another method is to distribute oil in portable tanks, which are filled in the oil house and wheeled into the mill, and discharge measured amounts of oil into the various cabinets.

In larger plants, padlocked oil cabinets are impracticable for main storage purposes, and a row of oil-storage tanks, usually cylindrical, are provided for the various grades of oil. It is good practice to have the tanks so arranged that barrels of oil can be placed above them when discharging and allowed to remain there until properly drained. Oil barrels may also be emptied by means of a hand-operated rotary pump or by compressed air; but it is difficult to empty them completely in this manner when the oil is very viscous, *e.g.*, heavy machinery oils or steam-cylinder oils.

The oil house should preferably be at a siding so as to save labor in delivering the oil. Where the consumption of one or several grades of oil is large enough to justify installation of the necessary storage capacity, the oil should be purchased in tank cars. The price is lower, and the labor of handling the oil and the empty barrels is saved, as the tank cars discharge straight into the storage tanks. Delivery of oil from storage tanks may be done by rotary pumps or compressed air or by self-measuring pumps. The tanks should be fitted with tank indicators or glass gauges, showing the amount of oil present. The indicators or gauges should be graduated to show the amount of oil in gallons, to facilitate stocktaking.

The oil is delivered from the oil house either in padlocked cabinets for departmental use or in oil jacks, say ½, 1, 2, or 5 gal. capacity. It should always be poured through a strainer when drawn from the storage tanks.

The amount of oil delivered is debited to the department concerned and totaled up at the end of each month. A careful entry must also be made of all supplies, and a check made every month to see whether the stock at the beginning of each month plus supplies received minus total amounts delivered tallies with the stock on hand at the end of the month. This will frequently be found not to be the case, and the source of leakage must be immediately traced and rectified.

Keeping a record of oil delivered does not, however, prevent waste. Securing full benefit from a proper storage and distribution system can be done only by someone, usually the chief engineer or master mechanic, who takes an intelligent interest in the amount of oil required for the various units throughout the works. Oil must never be delivered to any department in barrels or other receptacles that are not locked. There should be a system of daily or weekly allowance for each engine room or department, and the oil stores open only at certain stated hours. The fixed allowances should not be exceeded by the storekeeper, except on receipt of a special order, signed by the chief engineer.

Another system which is equally efficient, if he takes the necessary interest in it, is for the chief engineer on his daily round to give the engine attendants a check in duplicate for all oils required. The check is given to the storekeeper, and the engine attendant retains the copy.

The chief engineer should every month scrutinize the consumption sheets and revise the allowances, say, every 3 months. Heads of departments, foremen, overseers, etc., should receive a copy of the monthly consumption not only of his own departments but also of other departments, particularly if the conditions are similar, as this tends to create rivalry and reduce waste.

Empty barrels should be taken care of and returned when a sufficient number have accumulated to make a carload. Barrels that have contained black oils are rated as second class, whereas those which have contained engine or cylinder oils are rated as first class, and grease barrels as third class.

In works where no organized system of storage or distribution has been in use, and where some responsible person will take an intelligent interest in introducing proper methods, including regular allowances for every department, savings in cost of lubrication ranging from 10 to 30 per cent are often obtained, as a great deal of unnecessary waste is eliminated throughout.

Large oil firms employ experienced engineers for the purpose of assisting their customers in securing maximum economy of their lubricants. Most consumers will do well to avail themselves of such services.

CHAPTER XXXVI

CUTTING LUBRICANTS AND COOLANTS

In this section the author has made use freely of the material that he prepared for the Department of Scientific and Industrial Research.[1]

The part dealing with skin diseases was prepared by J. C. Bridge, H. M. Medical Inspector of Factories, Home Office, London, and is reprinted in the Appendix.

Cutting lubricants and cooling liquids—coolants—are oils or emulsions used in connection with the cutting of metal. They possess lubricating and cooling properties in different degrees, and the various classes into which they are divided may be defined as follows:

Soluble Oils.—The products known as soluble oils are oily liquids which form an emulsion when mixed with water.

Soluble Compounds, also known as Cutting Compounds.—Soluble compounds or cutting compounds are greasy pastes which form an emulsion when mixed with water.

Cutting Emulsions.—Cutting emulsions are aqueous emulsions formed by mixing soluble oils or soluble compounds with water.

Cutting Oils.—Cutting oils are oils such as lard oil, rape oil, or mineral oils or a mixture of such oils free from water and soap. These oils do not ordinarily form emulsions with water.

Cutting lubricants and coolants are used for the purpose of:

a. Cooling.
b. Lubrication.
c. Producing a smooth finish.
d. Washing away chips.
e. Protecting finished product from rust or corrosion.

a. Cooling.—During operation, the heat developed warms not only the tool but also the material that is being machined. On cooling, the latter will contract, and the dimensions will differ

[1] Published in 1918 by the Department for Scientific Research, London, in *Bulletin* 2, entitled "Memorandum on Cutting Lubricants and Cooling Liquids and on Skin Diseases produced by Lubricants."

from the measurements taken during the process of machining. The importance of properly cooling the product is, therefore, obvious, particularly under high-speed conditions and with materials, such as aluminum, that have a high coefficient of expansion.

If the tool heats too much, the cutting edge will wear rapidly. The heat generated at the point of the tool is conducted into the body of the tool. If the tool is of large section, the heat is more readily dissipated than is the case with a tool of light section. Efficient cooling of the tool edge reduces wear and enables a greater output to be obtained. This is most apparent with high-speed steel, the gain in cutting speed on steel and wrought iron being from 30 to 40 per cent and on cast-iron from 16 to 20 per cent. Efficient cooling of the shavings on the side not in contact with the tool is particularly important with tough material, as the difference in temperature between the two sides of the shaving causes contraction on the cold side and thus helps to reduce the friction produced by the shavings' rubbing over the nose of the tool.

b. Lubrication.—Lubrication is of little importance where the machined article is made of brittle material, as the material is removed in the form of powder or fine chips.

Lubrication is very important where the metal is tough and therefore removed in the form of spiral shavings, which grind their way over the nose of the tool. The character of the chips or shavings produced will depend upon the form given to the tool by grinding and also upon the angle at which it is used. The tougher the material the greater will be the metallic friction and the greater the necessity for lubricating the nose of the tool; otherwise, the shavings will produce great friction, resulting in rapid destruction of the tool and in rough finish.

c. Producing a Smooth Finish.—When the requirements of cooling and lubrication are satisfied the product will receive a good finish. Where a perfect finish is desired, experience has shown that cutting oils possessing great oiliness must be applied. For this reason various animal or vegetable oils, or rich mixtures of such oils with mineral oils, are usually employed. Some engineers find vegetable oils possessing great oiliness, such as rape or cottonseed oil, preferable to either mineral or animal oils in producing a very smooth finish. Dies, taps, reamers, and

form tools have a longer life when used on tough steel if a cutting oil is employed in place of an emulsion prepared from a compound or soluble oil. For finish boring, rifling, etc., a mixture of castor oil and mineral cleaning oil (gravity about 0.860 to 0.890) in the proportion of 3 parts of cleaning oil to 1 of castor oil has been used with good results. Although those oils do not form a homogeneous mixture, the addition of an equal volume of turpentine substitute (white spirit) causes perfect solution to take place and is said to be advantageous for finish turning on guns and other hard material.

For high-speed work it is always desirable that the cutting oil should have sufficient fluidity to ensure a rapid stream's being concentrated where required.

d. Washing Away Chips.—Frequently, the washing away of chips is quite an important function of the cutting lubricant or cooling liquid, particularly in cases of deep drilling, as in drilling rifle barrels, also in most milling operations.

If the cutting emulsion is used too weak, it will not carry away with it the minute particles of metal and scale, which may prove detrimental to the machine tool.

In the boring of deep holes, gun tubes, etc., a solution of sodium carbonate (50 lb.) and soft soap (25 lb.) in water (200 gal.) has been found to give very satisfactory results.

In solid deep-hole boring, where cutting emulsions are used, it is sometimes found that the emulsion, in filtering through the chips in the bore, becomes changed in character in such a manner as to lose some of its lubricating quality.

In the case of cast iron, considerable advantage may be obtained by using an aqueous emulsion in order to wash the dust away from the working parts and to prevent its dispersal in the air.

e. Protecting Finished Product from Rust and Corrosion.—Good cutting oils used straight, *i.e.*, not emulsified with water, will not cause rusting.

Cutting oils containing fixed oils (animal or vegetable oils) such as tinged lard oil, with a large percentage of free fatty acid, will cause verdigris on brass parts. Fixed oils containing only a small percentage of free fatty acid, such as rape oil or high-quality lard oil, when employed in cutting oils do not produce verdigris unless the oils are rancid.

Cutting emulsions made up from cutting compounds or soluble oils and water cause rusting if they are used too weak, or if they contain acid.

Emulsions of oil and water are not stable in the presence of even minute quantities of acid. Acid causes separation of an emulsion into layers of oil and water. The water settling out at the bottom where the pump suction is located is immediately circulated by the pump and causes rusting of the work. To a limited extent the emulsion can be reformed by adding a calculated quantity of ammonia sufficient to neutralize the acid, but any excess of alkali may facilitate corrosion of the metal being worked. Sodium chloride (common salt) and other salts act in much the same way as acid, in causing the emulsion to separate, only the action is less pronounced.

The admixture with a soluble oil of kerosene (5 per cent or more) prior to the addition of water has been reported to give good results. A thin film of kerosene forms on the top of all standing oil in barrels and tanks and prevents the access of air. Similarly, a thin film of kerosene forms over machined parts, machines, and tools which prevents gumming and rust. It should be noted, however, that the addition of kerosene to a soluble oil reduces its lubricating and emulsifying properties.

Emulsions must not be made by mixing soluble oils or cutting compounds with hard water owing to the precipitate caused by the action of the calcium and magnesium salts in such water. Soft water must be used, which may be rain water or distilled water or good-quality town water, or, if only hard water is available, it must be boiled or softened by chemical means and clarified.

APPLICATION OF CUTTING LUBRICANTS AND COOLANTS

The cutting lubricant may be applied by hand brush or oil-can, by drop feed from a reservoir fixed in a suitable position, or it may be circulated over and over again by means of a pump operated by the machine itself or independently operated, serving a group of machines.

The first two methods are used only for slow-speed work where cooling of the tools is of no importance. Practically all modern machines require, however, before everything else efficient cooling of the tools and the cut articles, as without such

cooling the high speed and output made possible by the employment of high-speed machine tools could not be taken advantage of to the full extent.

It will therefore be understood that what is usually required is a large volume of low-viscosity coolant (cutting emulsion or thin cutting oil) delivered as near as possible to the cutting edge of the tool or tools and delivered in a stream having a low velocity—large cross-sectional area—so as to avoid splashing. To deliver the coolant in a high-velocity thin stream does not ordinarily remove the heat effectively (an exceptional case where high velocity and pressure are required being that of "deep-drilling" work), and it causes a great deal of splashing, which means a very excessive consumption of cutting oil.

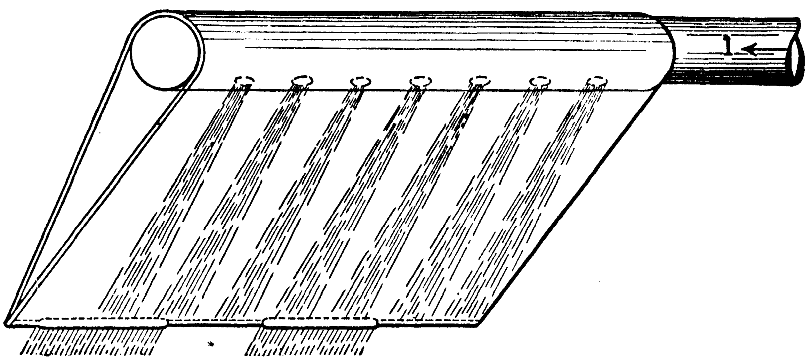


Fig. 229.—Cutting-oil distributor.

The delivery pipes should come as close to the tool-cutting edges as possible (sometimes flexible-tube delivery pipes are used with this object in view), and they should have *wide mouths* —flat bell mouths—to reduce the velocity of the delivered coolant.

A simple device embodying this principle is shown in Fig. 229. On the delivery pipe (1) with closed end is suspended a plate with its lower edges bent together, leaving openings, however, for discharging the coolant, which is delivered from holes in the underside of the pipe.

Great savings in consumption of cutting oil or coolants can be made in most machine shops by paying attention to the prevention of excessive splashing. The loss of cutting oil depends obviously also to a large extent on the viscosity of the oil.

As regards the type of pump to be used for circulating the coolant, plunger pumps have been practically discarded on

account of their pulsating discharge. Rotary-gear wheel-type pumps are now more widely used than the rotary-vane pumps and the centrifugal pumps. With the former two, a spring-loaded relief valve must be fitted in the discharge pipe to allow discharge back into the reservoir, when the delivery exits are closed. Rotary-gear pumps are often made so that they will deliver the coolant when running in either direction. Centrifugal pumps are very suitable for delivering large volumes of oil at low pressure and are not so easily choked as the rotary-gear or vane type of pumps.

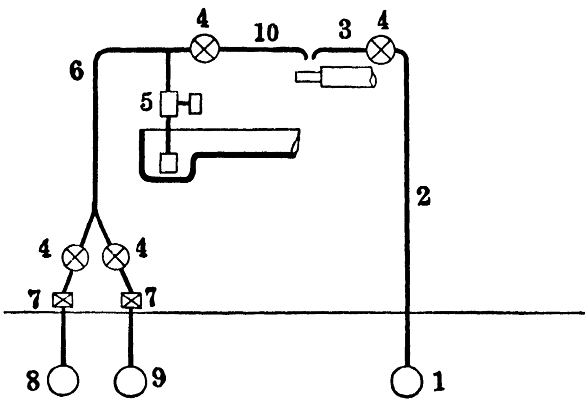


FIG. 230.—Cutting-oil circulation.

When a pump is not self-priming, a nonreturn valve should be fitted on the suction side, or the pump should *preferably* be submerged in the reservoir.

It is good practice to have a *large volume* of coolant in the circulation system, as it helps to dissipate the heat, and the coolant therefore keeps cooler.

When a group of machines are engaged on similar work, or their cutting-oil requirements are practically identical, they may with advantage be supplied from a common circulation system, with discharge pipes distributing the oil through branch pipes to each machine, the return oil passing through return pipes to a central tank, whence the oil is circulated afresh. Group systems with central tanks are excellent where one mixture is used on all machines on the circuit.

Return pipes should be large and should be arranged for easy access for cleaning. In large systems, isolating valves should be employed to sectionize the system. Efficient strainers should

be fitted on all return pipes and pump sections and should be cleaned daily. Tanks, as a rule, should be cleaned out every 6 weeks, and return pipes every 6 months. Any scum formed should be skimmed off the tanks daily.

It is important both with this system and where machine tools have individual pumps that the pump's suction should be always covered so that air cannot be drawn into circulation, since aeration of the circulating medium has a strong oxidizing effect upon the oil or emulsion.

When, however, the machine tools or the kinds of work done are of a varied character, it is necessary, when a circulation system is employed, to be able to cut out certain machines from the general supply so that they may use a separate quality of cutting oil or coolant and have their circulation system self-contained. Figure 230 is a diagram illustrating a supply system by Richardson-Phoenix Company of Milwaukee, Wis., which embodies this feature. The cutting oil is discharged from the 1½-in. delivery main (1) through ½-in. branch pipes (2) and a ⅜-in. service pipe (3) controlled by a gate valve (4). The used oil is lifted by a rotary pump (5) from the base chamber into the ¾-in. return branch pipe (6) fitted with gate valves (4) and check valves (7), delivering the oil either into the 3-in. steelwork return main (8) or the 3-in. brasswork return main (9), there being separate return mains and filtration tanks for the oil coming from the steelwork and brasswork section, respectively.

When a machine is cut out from the circulation system, the rotary pump circulates the oil through the ⅜-in. service pipe (10), the service pipe (3) being shut off by the gate valve (4). In America such systems are generally used, and their design may, of course, be adapted to the particular requirements of large machine shops. Mention should be made of the fact that filtration and sterilization of the return oil are features of many large plants. The filters are very much of the designs mentioned (page 594), but, in addition, chambers heated by steam coils sterilize the oil, heating it to about 200°F., and the oil returned from the steelwork section passes a magnetic separator, which is very effective in removing steel and iron particles but naturally has no effect on brass, aluminum, or other nonmagnetic metallic particles. The iron and steel chips adhering to the magnet may be automatically removed by scrapers fitted to an endless chain

which travels over the surface of the magnet, the chips dropping into a receiving vessel at the side.

Although filtration even through finely woven cloth will not remove the very finest particles, yet *well*-filtered oil appears to be quite satisfactory without the need of long-time separation by gravity in steam-heated settling chambers.

RECLAIMING OIL FROM SWARF

The consumption of cutting oil is made up of various losses, principally those due to oil splashing away from the machines,

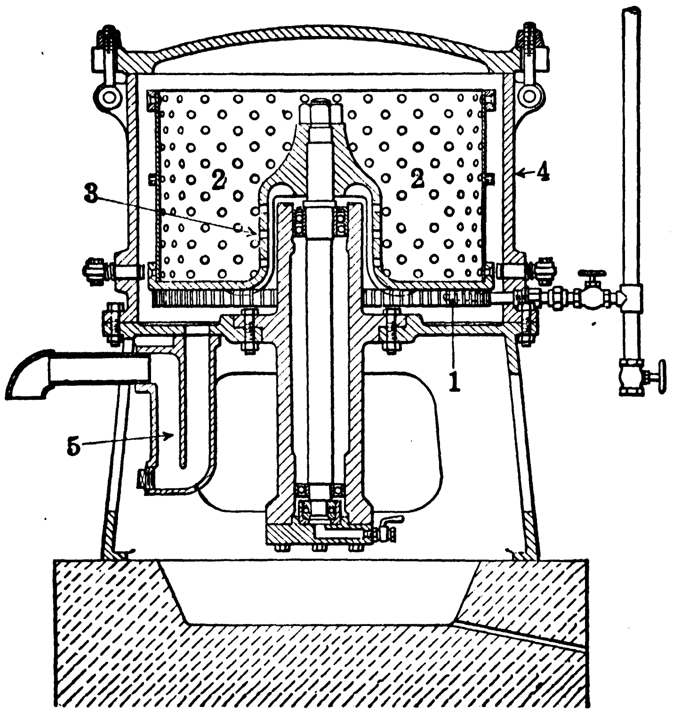


FIG. 231.—Separator for oil recovery.

1. Steam nozzle.
2. Revolving cage.
3. Perforations in the dome admitting steam to cage; useful when removing oil from waste.
4. Exterior stationary chamber.
5. Siphon for oil discharge.

as already mentioned, and oil adhering to the swarf chips and turnings.

In the case of cutting emulsions the swarf drains fairly clean by gravity alone; but when cutting oils, particularly if they are viscous, like lard oil, are used straight, a large amount adheres to the swarf. From 50 to 80 per cent of the daily consumption can be saved by reclaiming cutting oil from the swarf in separators operating at high speed, the peripheral speed being as high as 6,000 to 7,000 ft. per minute. Figure 231 illustrates a turbine-driven machine; smaller machines are mostly belt driven. The

turbine is of the De Laval type. The steam has a slight emulsifying effect on compounded cutting oils, so that in this respect belt-driven machines are preferable. When removing oil from wiping materials (for which these separators are also used), the presence of steam helps to liquefy the oil and thus separate it more completely from the wiping material, the recovery of which is the prime object.

Steam of 20 to 40 lb. pressure is generally employed. The wiping material is afterward washed and dried. The clean swarf is remelted on the works or sold.

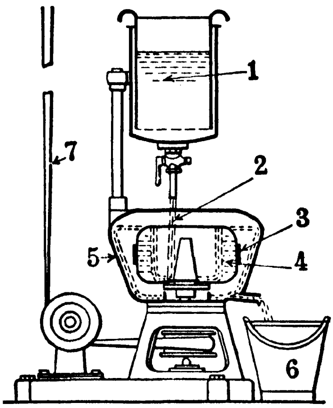


FIG. 232.—Spratt's oil purifier.

1. Dirty-oil receptacle.
2. Oil feed into revolving cage.
3. Revolving cage.
4. Water.
5. Outer, stationary chamber.
6. Purified-oil receptacle.
7. Belt drive.

The reclaimed oil is dirty, containing fine metallic particles in suspension, and must be further purified by heating in large settling tanks where the metallic impurities and emulsified oil separate out by gravity alone; or it must be well filtered. It cannot very well be completely purified by separators, as the very finest particles float like fine dust in the oil and take a long time to separate out.

Spratt's separator used for purifying oil is shown in Fig. 232.

Sufficient water 4 is first of all poured into the cage (3) to form a vertical cylindrical wall, when the cage revolves. The oil rises in a thin film up this wall and is thrown out at the top, while the heavy impurities leave the oil film, dive through the water, and collect on the inside of the cage, whence they can be removed at intervals.

SELECTION OF CUTTING LUBRICANTS

Before selecting the correct grade of cutting lubricants it is necessary to consider several important factors such as:

1. Cutting speed and depth of cut.
2. The material under manufacture.
3. The system of application of the lubricant or emulsion.
4. The production of skin diseases (see pages 625–627).

1. Cutting Speed and Depth of Cut.

Low Speed and Shallow Cut.—Low speed and shallow cut require little cooling and little lubrication.

Low Speed and Heavy Cut.—Low speed and heavy cut, particularly if the material is tough, demand a cutting lubricant possessing great oiliness.

High Speed and Shallow Cut.—High speed and shallow cut demand a cutting medium with great cooling properties; consequently emulsions are frequently used. Where a perfect finish is desired, low-viscosity cutting oils are used straight.

Where the speeds are particularly high, emulsions only should be used, as otherwise there will be excessive heating of the tools and of the product. A mixture of kerosene with lard oil or other cutting oil for high-speed work in connection with aluminum has given good results but is somewhat dangerous and has led to several fires. It is perhaps better to use cutting emulsions which possess the necessary cooling properties and are not inflammable.

High Speed and Heavy Cut.—High speed and heavy cut demand a cutting lubricant with great cooling as well as lubricating properties, so that heavily compounded cutting lubricants of low viscosity must be used. Low viscosity is necessary to give good cooling effect, and heavy compounding with animal or vegetable oils is requisite so as to lubricate the tools and shavings effectively and prevent wear as far as possible. A rich emulsion produced from an oil containing a high percentage of vegetable oil has also proved satisfactory, as the excellent cooling properties of the rich emulsion compensate for its lower degree of oiliness as compared with heavily compounded cutting oils used straight.

2. Material under Manufacture.—The influence of the material upon the choice of cutting oil has already been referred to.

Where material is brittle, cutting emulsions are nearly always used, as very little lubrication is required. When cutting oils are used, there will be no need for any compounding with fixed oil, so that straight mineral oils may be employed.

The amount of soluble oil or soluble compound used for preparing the cutting emulsion varies from 2½ to 20 per cent, the

APPENDIX

SKIN DISEASES PRODUCED BY LUBRICANTS

By J. C. Bridge

1. Oil Rashes.—Oil rashes are, generally speaking, of two kinds: the first is due to plugging of the small glands at the root of the hairs on the arms and legs of workers; the second, to mechanical injury to the skin produced by metallic particles suspended in the cutting lubricant.

a. Plugging of the Glands of the Hair Follicles.—Primarily, this is purely mechanical; a mixture of oil and dirt blocks the minute openings of these glands and sets up inflammation round the hair (folliculitis). The inflammation begun in this way may lead on to suppuration or abscess formation (a boil). If many hairs are affected, the arm presents an appearance of a crop of raised red spots (papules) with a black spot as a center or, if the inflammation has gone as far as suppuration (abscess formation), a yellow head.

b. Mechanical Injury to the Skin by Metallic Particles.—Minute metallic particles suspended in the cutting lubricant may produce injury to the skin. This occurs chiefly on the hands, where two surfaces are rubbed together, *e.g.*, the skin between the fingers. Injury to the skin may also be produced on any part of the hands and arms by wiping with a cloth or rag while the hands or arms are coated with a film of fluid in which metallic particles are suspended. Injury to the skin allows germs to enter and causes septic infection.[1]

2. Prevention. *a. Cleanliness of the Worker.*—Washing accommodation for workers in contact with oil must be on a liberal scale. Hot water, soap, and scrubbing brushes are essential.

[1] Blood poisoning has also been caused by bacteriological infection of gluey moisture present in the cutting oil.

Barrels after exposure have become soaked with moisture which spread the infected glue throughout the oil (objectionable odor), so that wherever this oil afterward came in contact with the workers (hands, arms, thighs), even including the storekeeper, blood poisoning set in.

Workers should be instructed not to wipe their hands on rags, etc., before washing and to avoid washing their hands in the cutting compounds.

Ether soap, which dissolves oil, has been found useful in preventing inflammation of the hair follicles. Dusting the arms with a powder containing equal parts of starch and zinc oxide before beginning work prevents the action of the oil on the skin.

b. Cleanness of the Lubricant.—Care must be taken in the handling of the constituents before blending that they have not undergone changes, *e.g.*, formation of free fatty acid.

Constant removal of metal particles is necessary to avoid injury to the skin. Filtration, such as is provided on the machines, and centrifugal action are insufficient to remove the minute metal particles which may injure the skin. Where cutting oils (straight oils) are used, their viscosity can be diminished by heat sufficiently to allow the particles to sink without affecting their value as lubricants. This operation completely removes all metal particles. In other lubricants where such a procedure is impossible it is necessary constantly to change and renew the cutting lubricants.

c. Cleanness of the Machines.—Frequent cleaning of the machines with the removal of all the old lubricant from all parts of the machine is essential.

3. Addition of Disinfectants or Antiseptics to the Lubricants.—Various antiseptics, Lysol (1 to 2 per cent) being the most common, have been added to the lubricant to prevent rashes, and in the case of cutting emulsions 0.5 per cent of disinfectants soluble in water have been used for this purpose. The results obtained have not been altogether satisfactory, and reliance cannot be placed upon such a method to prevent skin rashes.

4. Sterilization by Heat.—It has been suggested that the cutting oil be heated to 300°F. for a short period with a view to sterilizing it as well as to increase its antiseptic or germicidal action.

Laboratory experiments in America have shown that used oil possesses rather marked germicidal effects; and in view of the fact that the used oil becomes heated during use, attempts were made to determine whether heating new oil would also bestow upon it germicidal powers. Apparently, heating does produce such a change, but the temperature required is upward of 125°C.

The actual temperature required to produce this germicidal action in the oil has not yet been determined, but it has been recommended to mix new oil with the used oil before filtering and heating, so that the new oil may possess to some extent the germicidal power of the used oil.

5. Removal of Workers with Septic Infection of the Hands.—Workers whose hands become the seat of septic infection should not be allowed to work on machines, as they are liable to infect the oil with germs and so infect other workers.

6. Treatment. *a. Folliculitis Produced by Blocking of the Glands.*—As a general rule, frequent washing with soap and hot water is sufficient to produce a rapid cure. The skin may be subsequently dusted with zinc oxide and starch powder.

It has been found that, where this is insufficient, a mild antiseptic applied on lint has relieved the irritation and given good results.

b. Septic Infection of the Skin Due to Cuts.—Septic infection should be treated on general principles by the application of suitable antiseptic dressings.

7. Susceptibility.—Certain individuals appear to be particularly susceptible to the action of lubricants.[1] Such persons when found should be removed from contact with oil.

[1] Bad health, weakness following upon illness, delicate skin, etc.

INDEX

L

M

W

Y